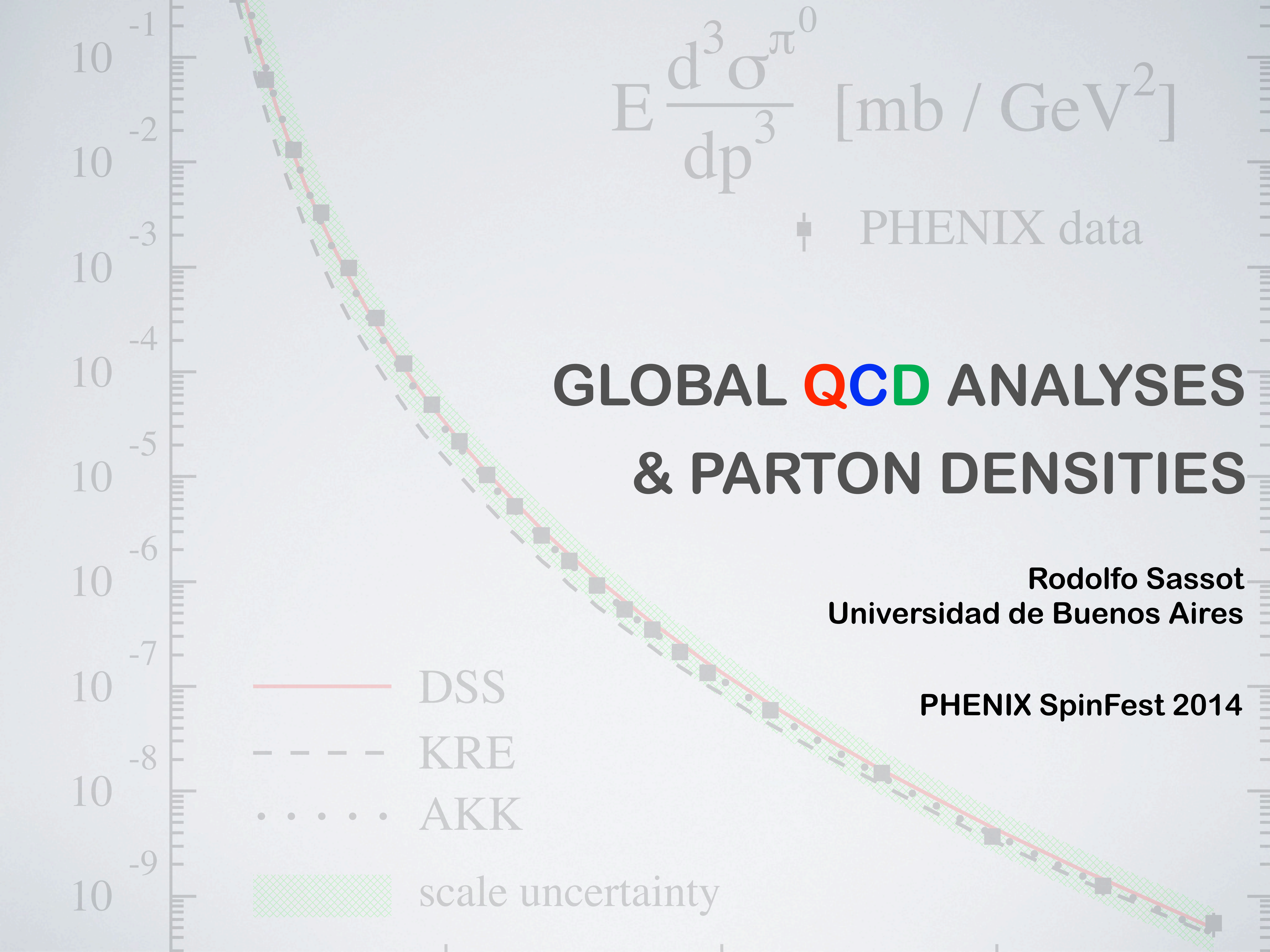
GLOBAL QCD ANALYSES & PARTON DENSITIES

Rodolfo Sassot
Universidad de Buenos Aires

PHENIX SpinFest 2014



Fourth Lecture: Nuclear PDFs (nPDFs)

4.0 Prehistory of nPDFs

Experimental and theoretical framework in early '80s

Motivation for studying nuclear effects at high energies

4.1 History of nPDFs

pQCD inspired frameworks, factorization

First nPDFs extractions

4.2 Present status

modern nPDFs: EPS09, nCTEQ, DSSZ

medium modified FFs

4.3 Future of nPDFs

dA (pA) experiments at RHIC (LHC)

Outlook

4.0 Prehistory of nPDFs

no much interest in partons
in nuclei before 1982:

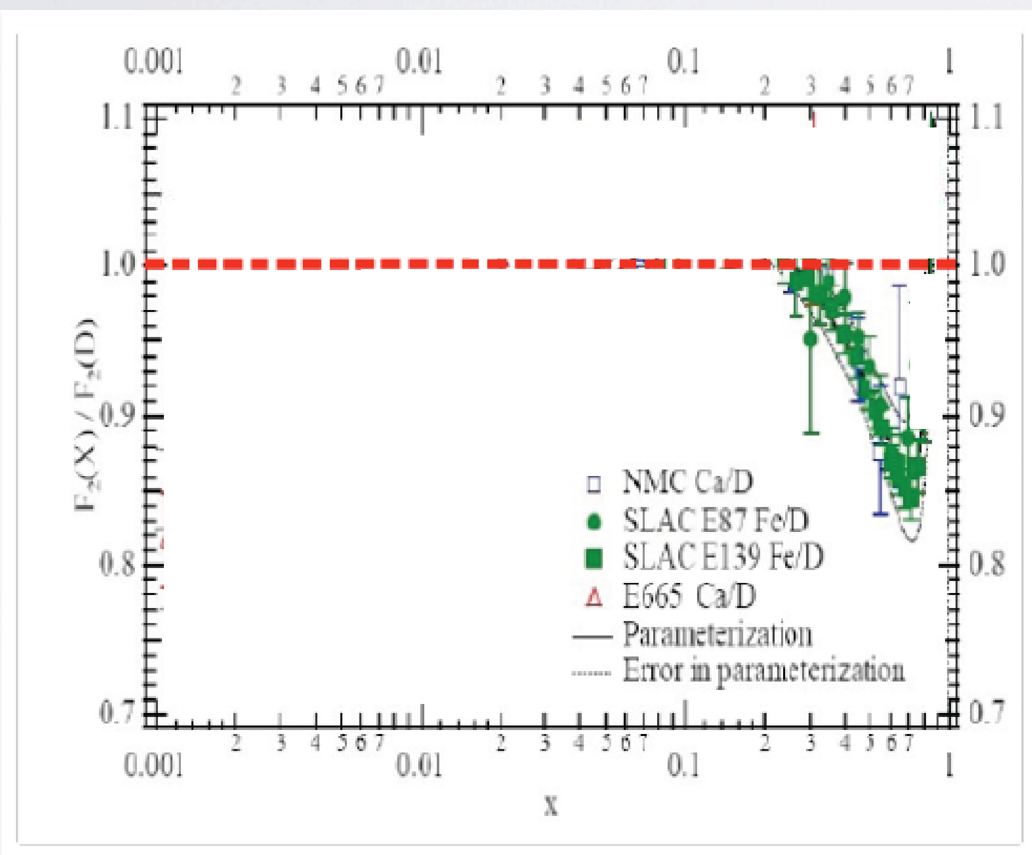
accurate models for nuclear structure

low energy scales "freeze" QCD dof

DIS "incoherence" hypothesis

$$F_2^A \simeq Z F_2^p + (A-Z) F_2^n$$

European Muon Collaboration (EMC)



$$\frac{\frac{1}{A} F_2^{Fe}}{\frac{1}{2} F_2^d} \neq 1$$

incoherence?
only nucleons?
free=bounded nucleons?

interesting in itself but also:

- no neutron targets/beams
- neutrino scattering

PDFs

- pA, dA baseline for AA
  at RHIC and LHC

QCD matter

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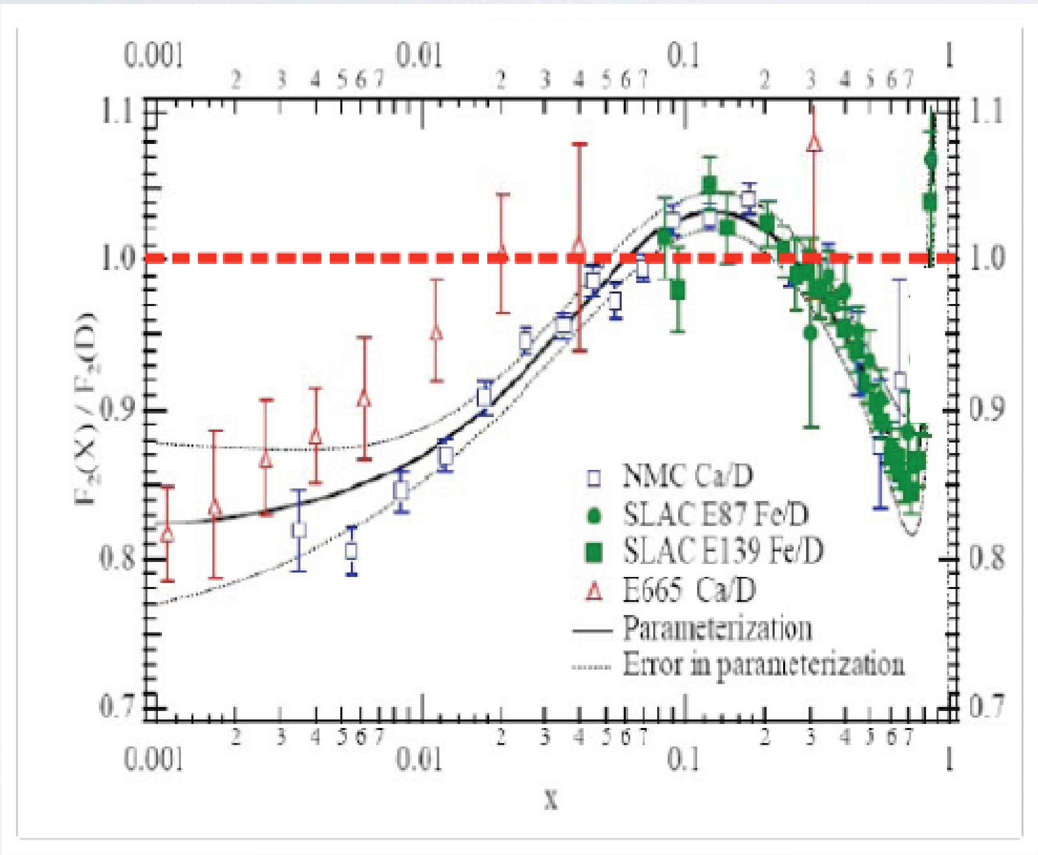

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PDFs

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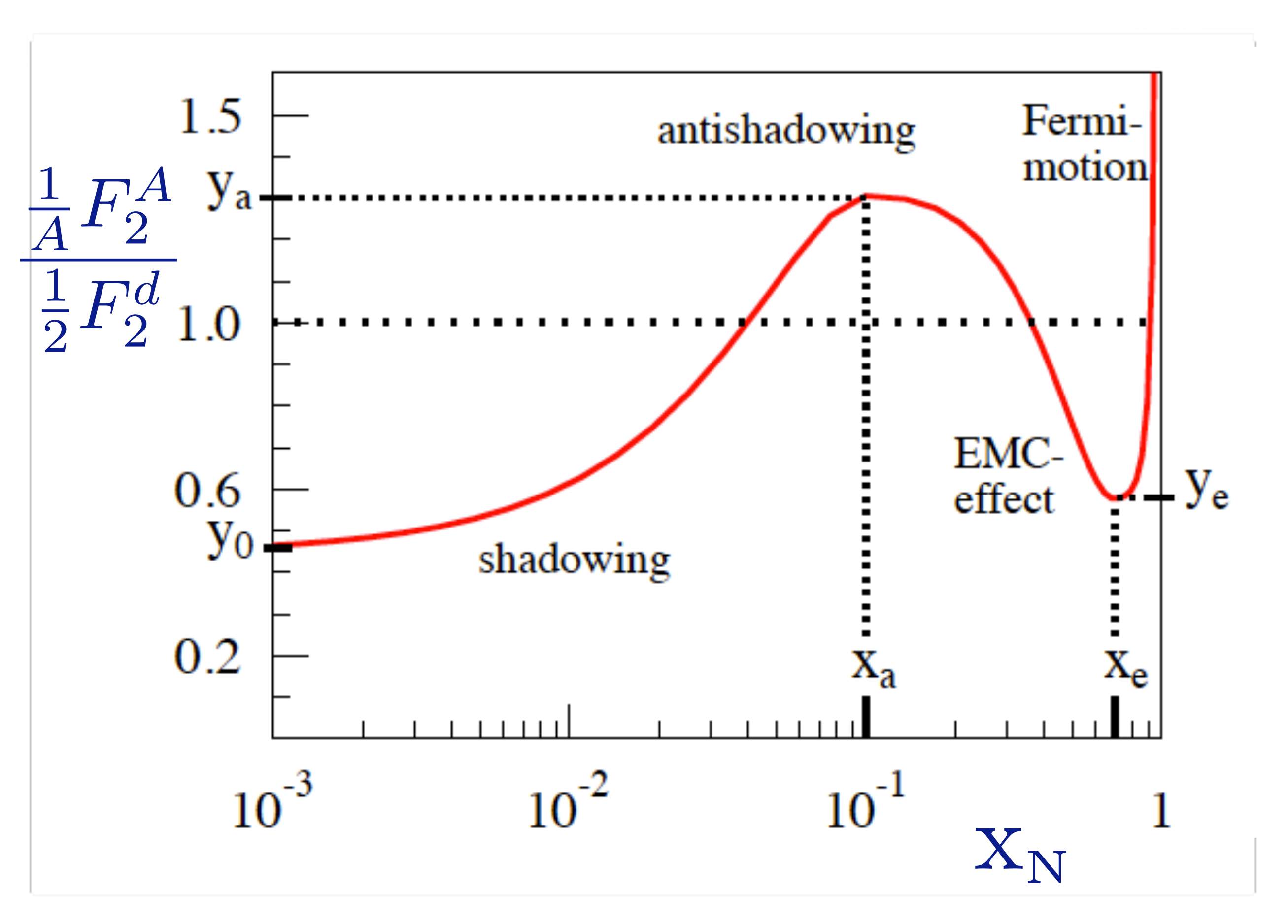
QCD matter

4.0 Prehistory of nPDFs

what is going on?

no universally accepted explanations yet



Fermi motion

- collective motion of nucleons inside the nucleus
- enhances "scattering" around & beyond (!) kinematic limit for free proton

nuclei	$x_A = \dfrac{Q^2}{2p_A \cdot q}$	$0 < x_A < 1$
per nucleon $p_N = p_A/A$	$x_N = \dfrac{Q^2}{2p_N \cdot q}$	$0 < x_N < A$

EMC effect

- ~binding mechanism: if it borrows p_N, works
- non-nucleonic d.o.f. (pions, multi-quark clusters, ...)
- many models for bound nucleons

anti-shadowing

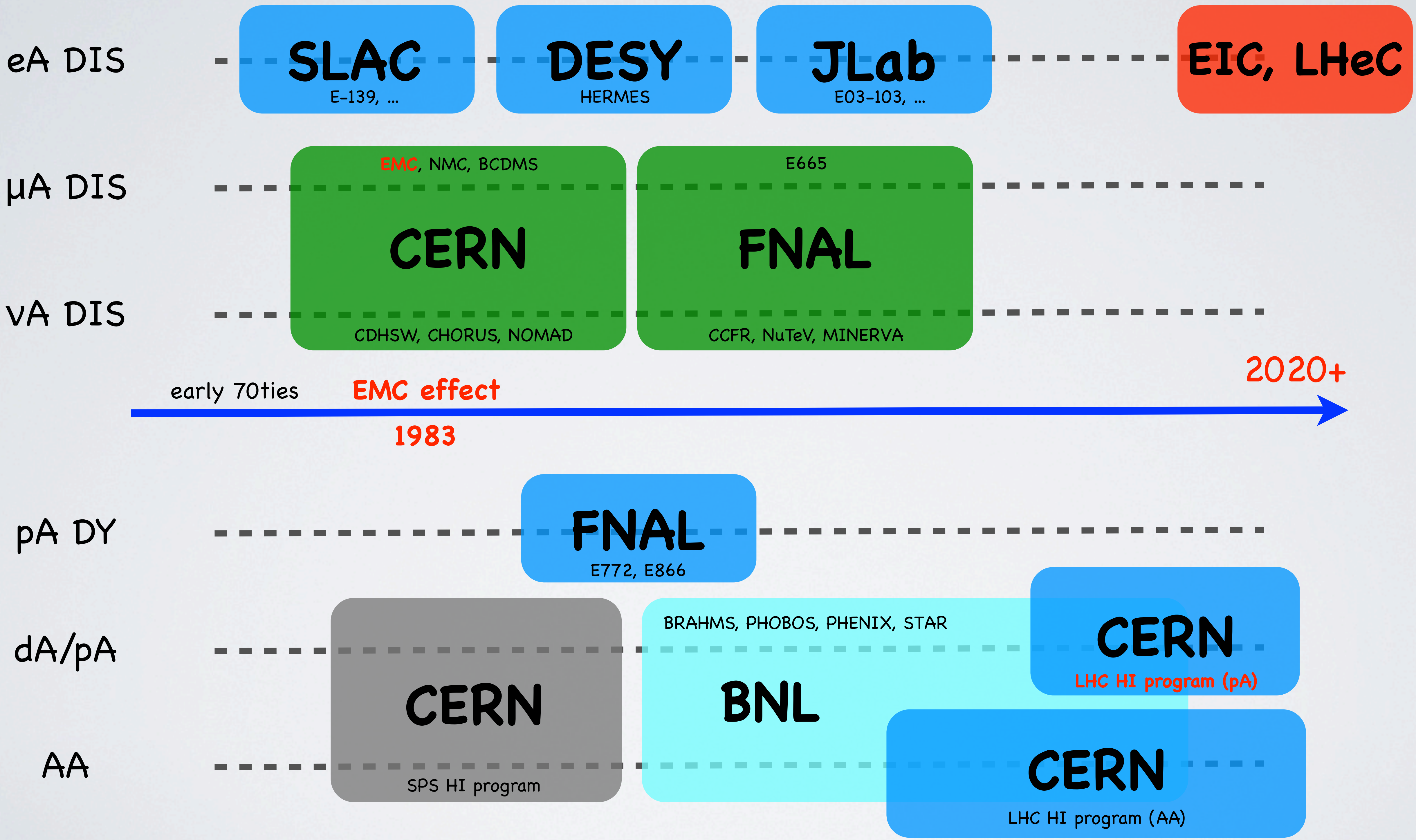
- momentum and baryon number conservation
- partons (from different nucleons) recombine/fusion

shadowing

- interpreted as coherent interaction with more than one nucleon, many models
- effect known in hadron-nucleus total cross sections; optical analogy: surface nucleons shadows inner ones
- intermediate states: elastic (Glauber) vs inelastic (Gribov)
- low x~parton overlap~recombination~saturation

4.0 Prehistory of nPDFs

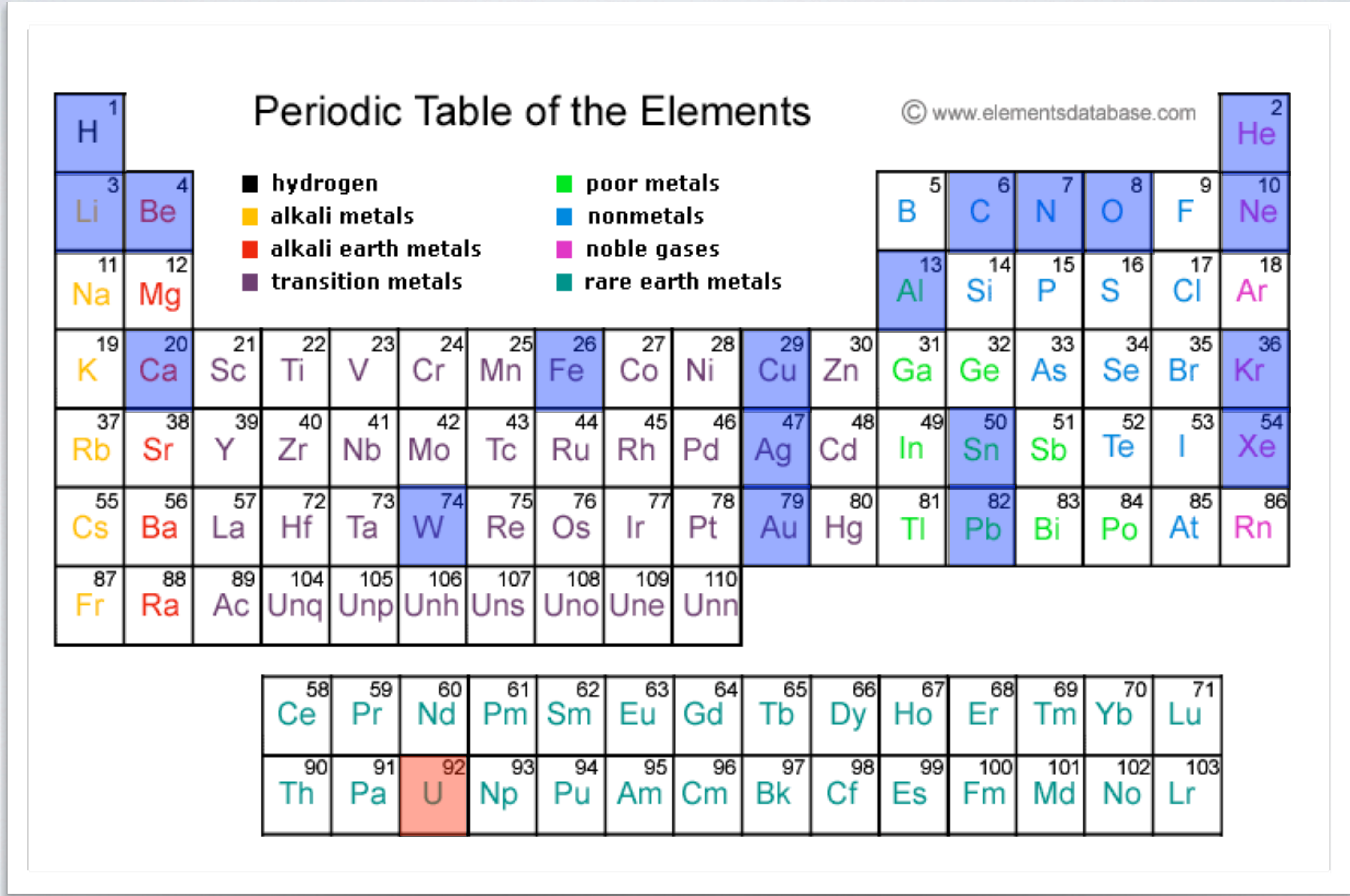
vigorous experimental programs since the early seventies



no eA collider yet

4.0 Prehistory of nPDFs

many different nuclei studied over the years → **picture of A dependence**



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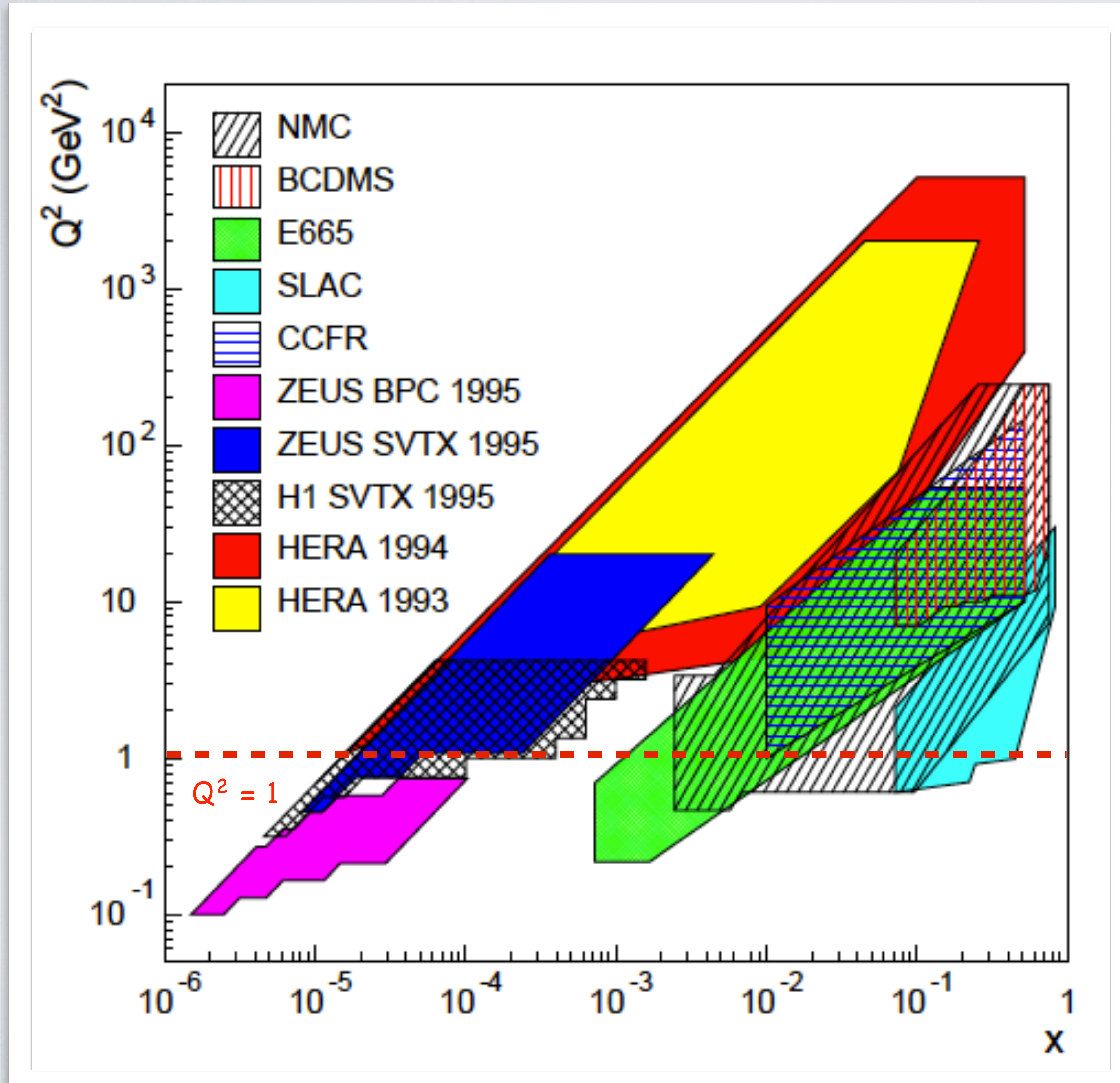
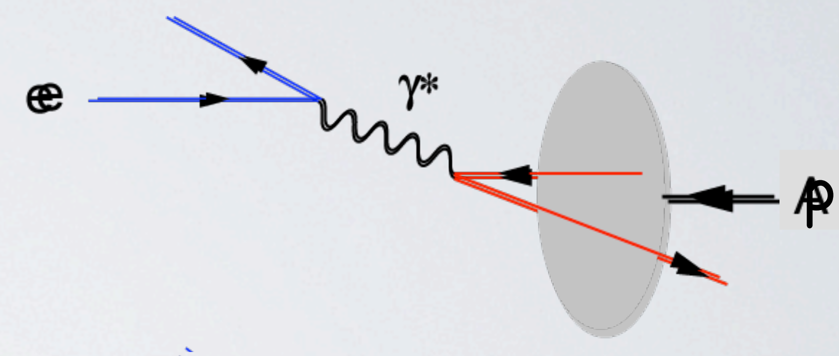


current kinematic coverage for electron-proton DIS

much more limited coverage in eA DIS



yet the best constraint for nPDFs

determines small-x behaviour of quarks and gluons in all analyses of proton PDFs

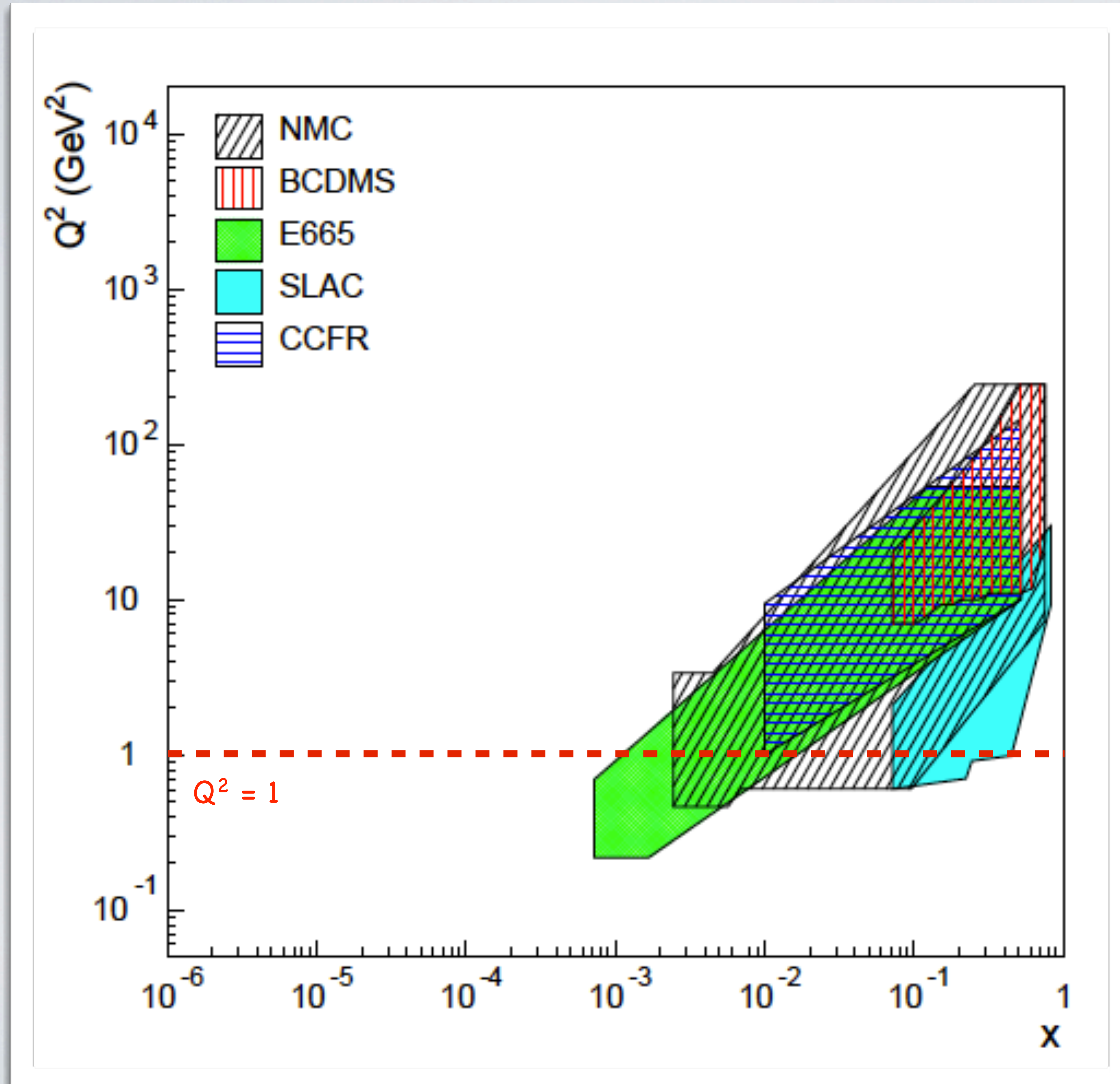
- low x, low Q^2
  where saturation is relevant
- high Q^2
  to test scale evolution

an electron-ion collider

(EIC, LHeC projects)

is in high demand

4.0 Prehistory of nPDFs



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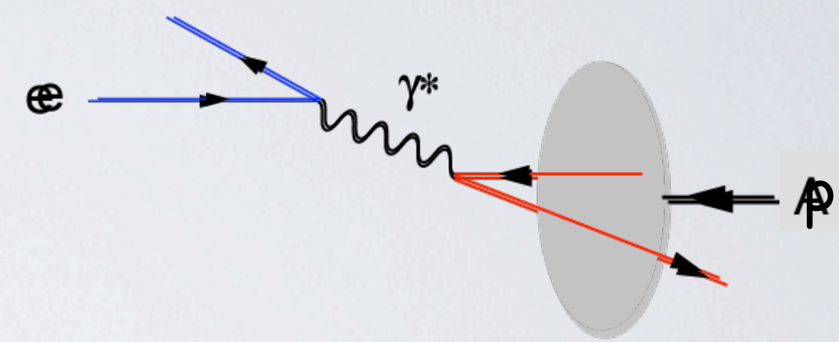

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an electron-ion collider
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4.1 History of nPDFs

does a pQCD inspired framework work?

we calculate — we measure / fit / model

➥ factorization between short and long distances

nPDFs definition

$$d\sigma_A = d\hat{\sigma}_i \otimes f_i^A$$

nPDFs parameterization

input scale — O(1 GeV)

$$f_i^A(x_N, Q_0^2) = R^A(x_N, Q_0^2)\, f_i^N(x_N, Q_0^2)$$

free proton

e.g. multiplicative — choose ansatz and determine from data

e.g. from scratch

e.g. convolutions

f_i^A includes all nuclear effects

fitted to data

standard nPDFs

$$d\sigma_N = d\hat{\sigma}_i \otimes f_i^N$$ PDF

standard partonic cross section → standard DGLAP evol. eqs. for nPDFs

known cross sections
known path to higher orders
universality

alternative schemes

"something else"

~medium effects: higher density
non linear
confinement size
Λ_{QCD} . . .

→ non-standard evol. eqs. for nPDFs

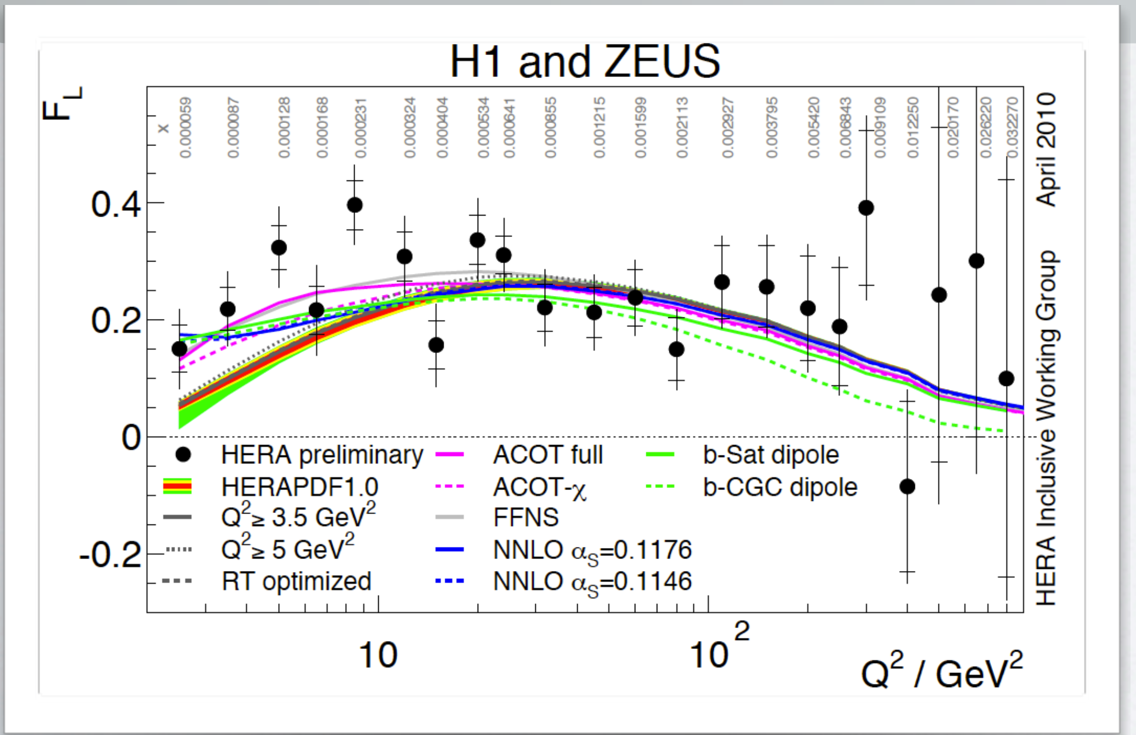
theorist's favorite playground

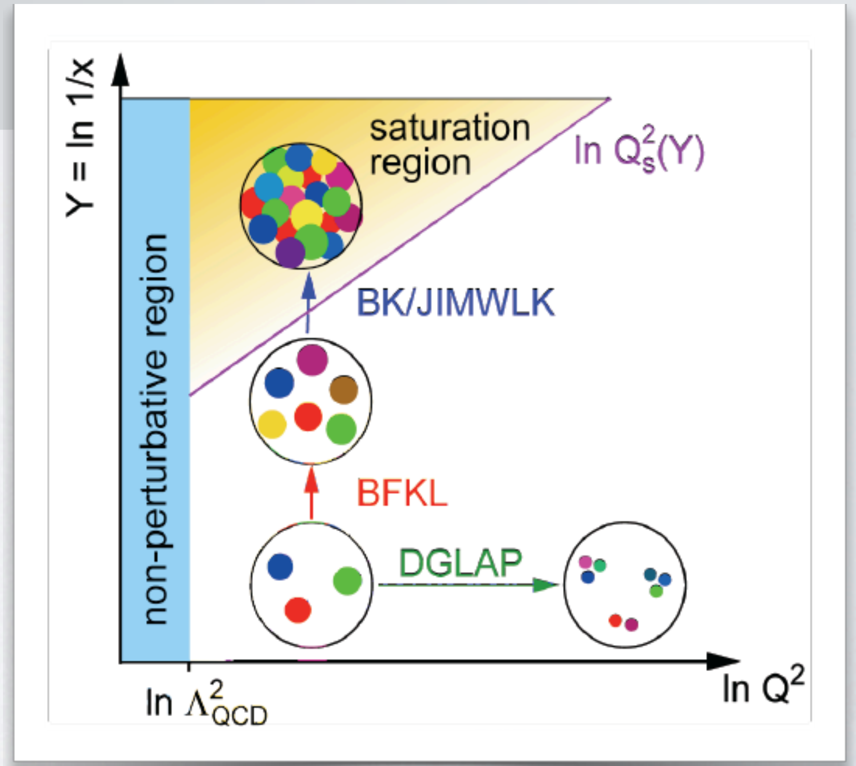
other processes?
higher orders?
consistency?

4.1 History of nPDFs

what do we want to learn from nPDFs?

- nPDFs can parametrize nuclear effects with little bias and without assuming certain "mechanisms" to model the observed modifications/effects
  link to models of nucleon structure at low scales and proposed nuclear modifications
- a global QCD analysis of many hard probes will reveal tensions due to the assumed framework
  factorization and/or DGLAP evolution will eventually break down: where?
- map out kinematic regime where nPDF framework applies and study transition to saturation region



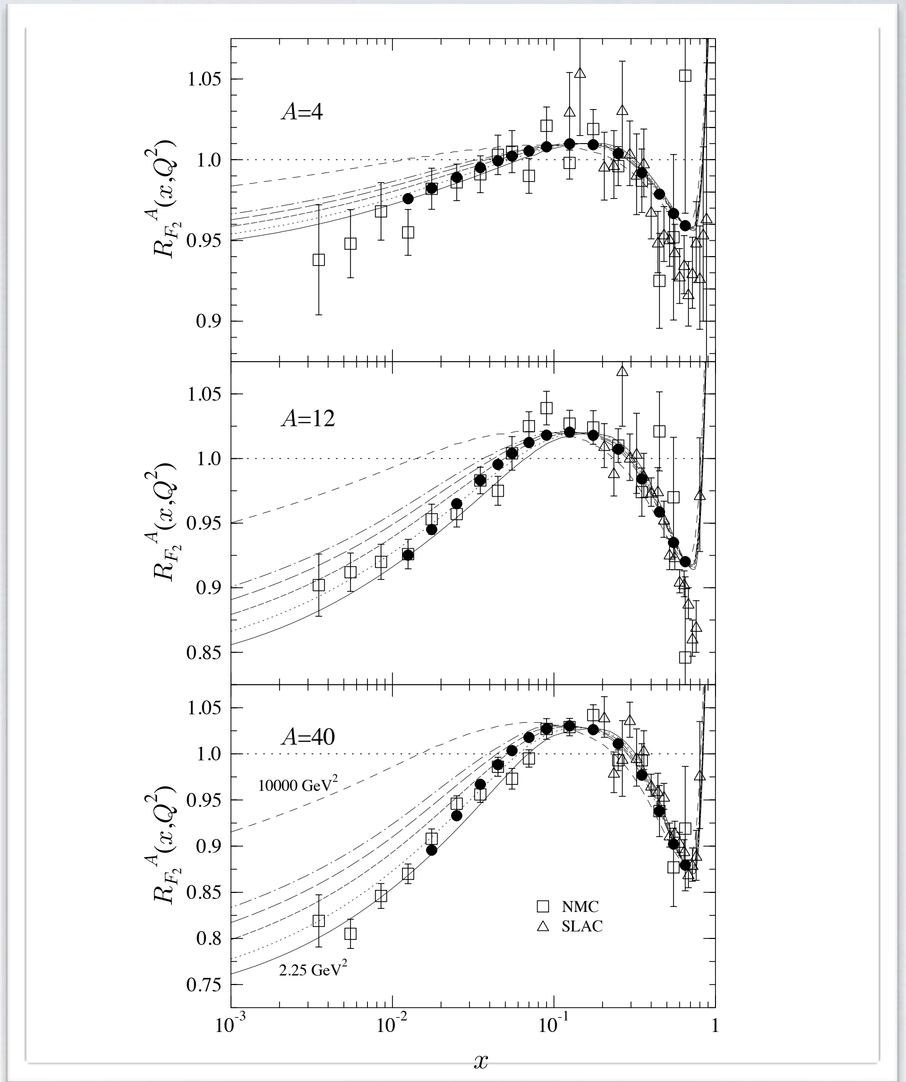


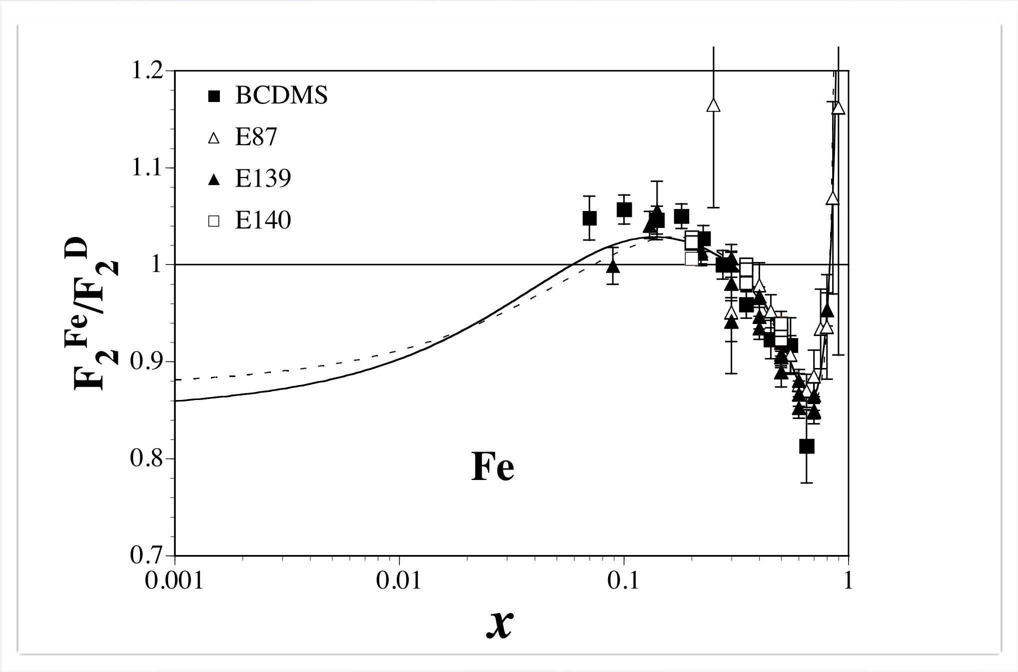
- no unambiguous hints for saturation in ep down to $x = 10^{-5}$
- transition often characterized by "saturation scale" $Q_s(x,A)$
- non-linear effects (recombination) demanded by unitarity

4.1 History of nPDFs

EKS Eskola, Kolhinen, Salgado - hep-ph/9807297
Eskola, Kolhinen, Ruuskanen - hep-ph/9802350

- **first LO analysis**
- NMC, E665 DIS and E772 Drell Yan
- standard multiplicative ansatz
- no error analysis (no χ^2)





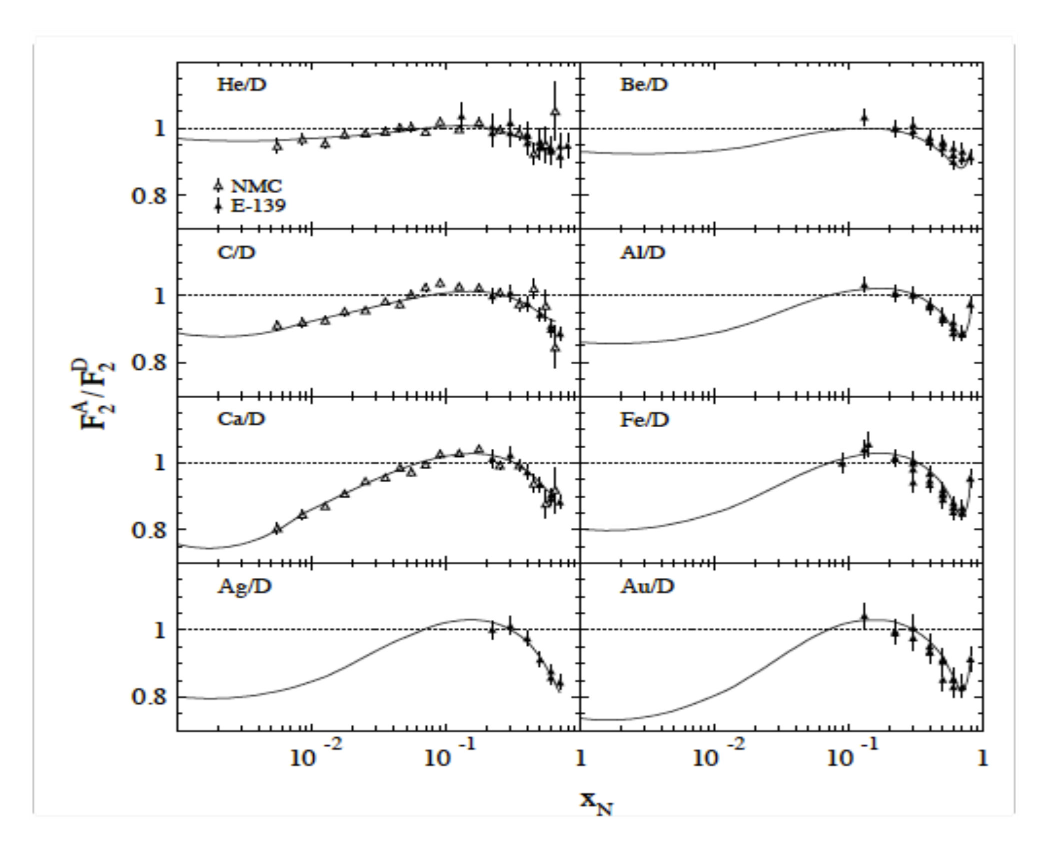
HKN Hirai, Kumano, Nagai - hep-ph/0103208

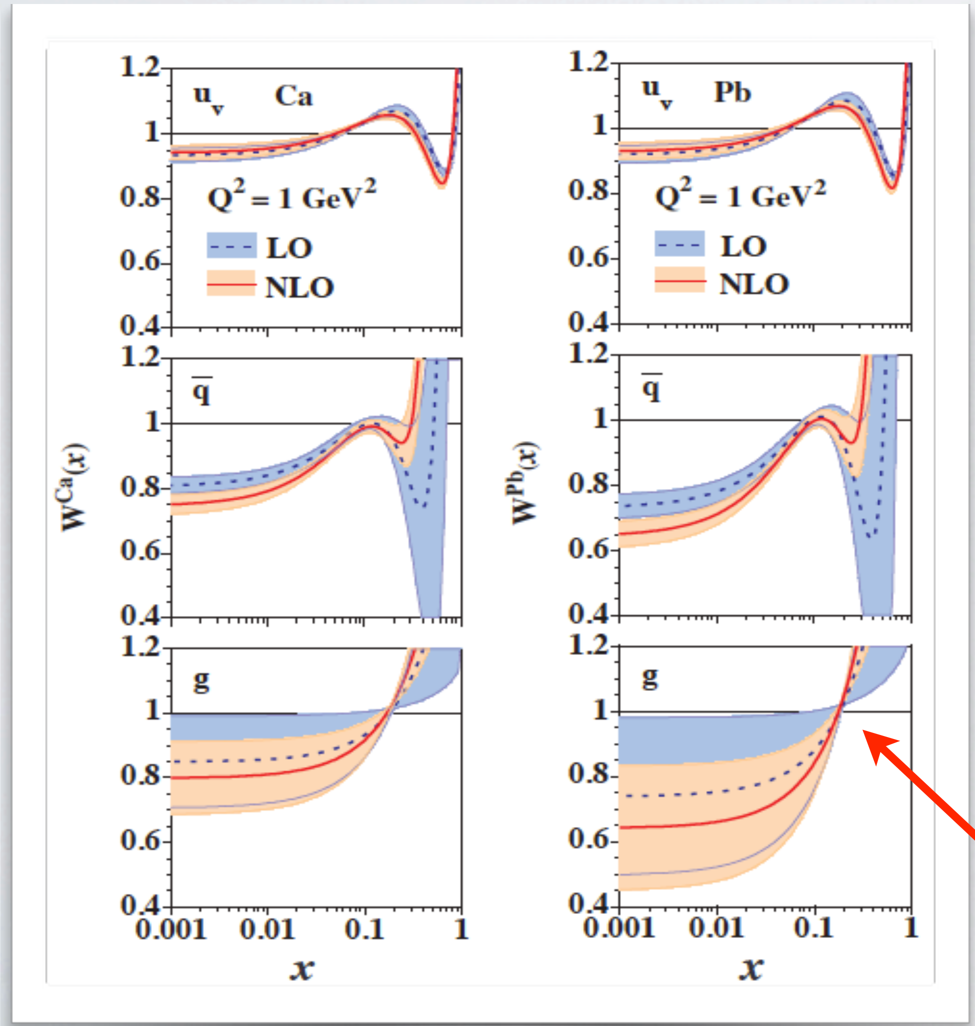
- **LO analysis** (first χ^2 minimization)
- EMC, NMC, SLAC, E665 DIS $\quad \chi^2/\mathrm{d.o.f} = \mathbf{1.76}$
- standard multiplicative ansatz
- no error analysis

4.1 History of nPDFs

nDS de Florian, R.S. - hep-ph/0311227

- **first NLO analysis** $\chi^2/\text{d.o.f.} = \mathbf{0.74}$
- only SLAC & NMC DIS sets and some DY data
- convolutional approach in Mellin N-space
- no error analysis





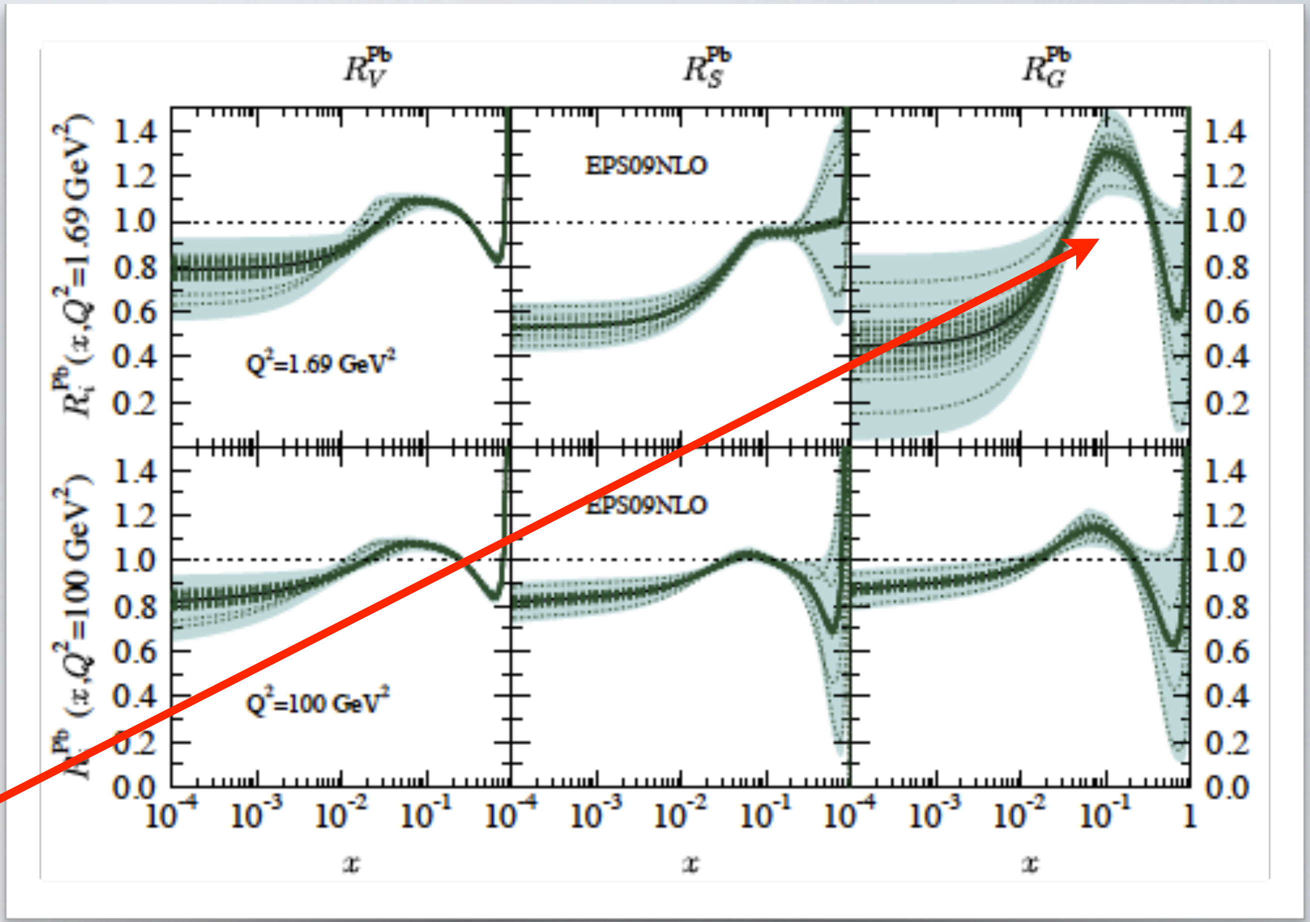
HKN Hirai, Kumano, Nagai - arXiv:0709.3038

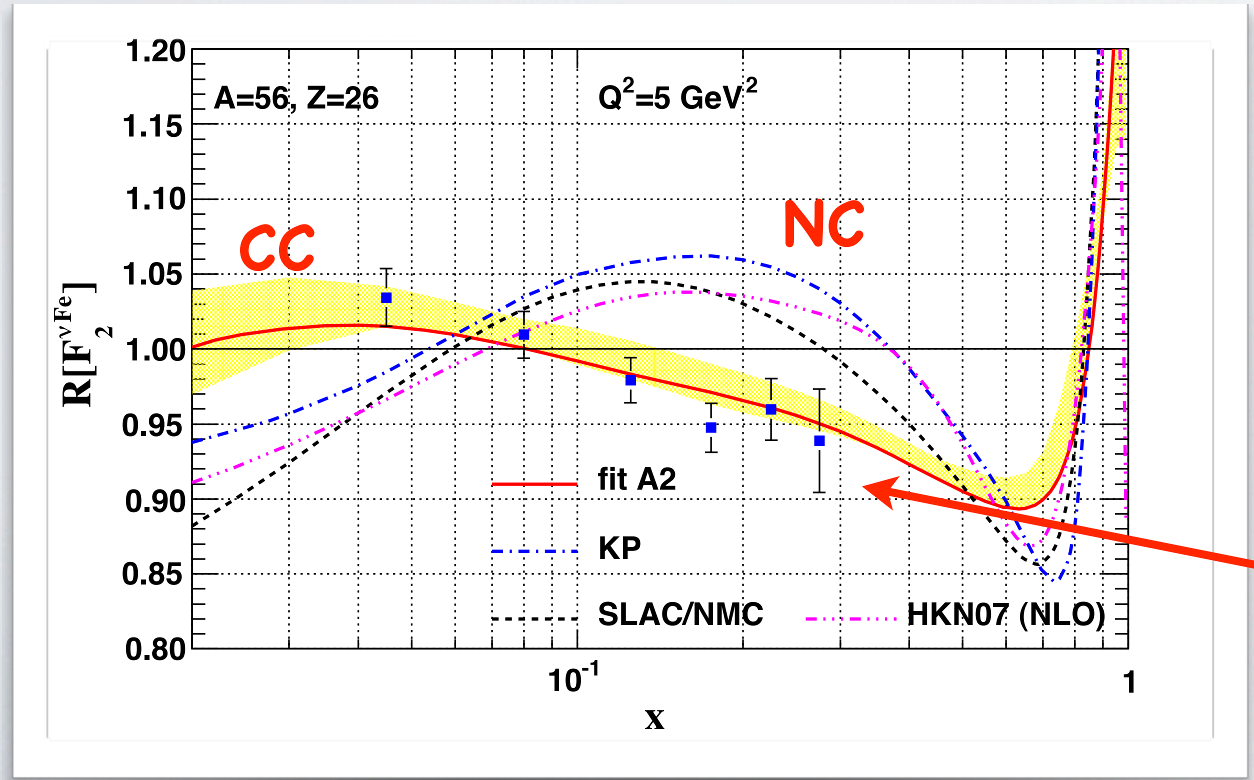
- LO and NLO analyses $\chi^2/\text{d.o.f.} = \mathbf{1.2}$
- standard DIS and DY data sets
- standard multiplicative ansatz
- **first error analysis** (Hessian method)
- rather "unusual" gluon distribution at large x

4.2 Present status

EPS Eskola, Paukkunen, Salgado - 0902.4154

- NLO analysis $\chi^2/\mathrm{d.o.f.} = \mathbf{0.8}$
- usual DIS & DY data
- **RHIC dAu data to constrain gluon better**
- complicated piecewise multipl. ansatz
- Hessian error analysis
- huge anti-shadowing/EMC effect for gluon





nCTEQ Keppel, Kovarik, … - 0907.2357

- direct ansatz a la CTEQ
- DIS & DY plus **CC neutrino DIS data**
- find tension between NC and CC DIS data

breakdown of factorization

4.2 Present status: DSSZ

de Florian, R.S., Stratmann, Zurita - 1112.6324

why do we need yet another set of nPDFs ?

- no truly global analysis yet
  - ➥ *include charged lepton DIS, Drell-Yan, CC neutrino DIS, and RHIC dAu data*
- use up-to-date proton PDFs as reference set
  - ➥ *many different sets to choose from - take MSTW*

    Martin, Stirling, Thorne, Watt - arXiv:0901.0002
- improve on the treatment of heavy flavors
  - ➥ *e.g. NLO massive Wilson cross sections for CC DIS*

    Blumlein, Hasselhuhn, Kovacikova, Moch - arXiv:1104.3449
- provide some estimate of nPDF uncertainties

main questions to address

- do we really see a tension between charged lepton and neutrino DIS data?
- do RHIC dAu data imply strong modifications of the nuclear gluon distribution?

DSSZ: x-dependence

- use multiplicative nuclear modification factor $\mathbf{f_i^A(x, Q_0) = R_i^A(x, Q_0) \times f_i^p(x, Q_0)}$
- initial scale **Q_0 = 1 GeV**, NLO DGLAP evolution to all other scales $Q > Q_0$
- parametrize both valence distributions as

needs to be flexible enough to accommodate (anti-)shadowing, EMC effect, Fermi motion

$$\mathbf{R_v^A(x, Q_0) = \epsilon_1 x^{\alpha_v} (1-x)^{\beta_1} \times [1 + \epsilon_2 (1-x)^{\beta_2}] \times [1 + a_v (1-x)^{\beta_3}]}$$

- data do not allow to discriminate different sea quark flavors (tried in analysis)

$$\mathbf{R_s^A(x, Q_0) = R_v^A(x, Q_0) \frac{\epsilon_s}{\epsilon_1} \frac{1 + a_s x^{\alpha_s}}{a_s + 1}}$$

- need another modification factor for gluons

$$\mathbf{R_g^A(x, Q_0) = R_v^A(x, Q_0) \frac{\epsilon_g}{\epsilon_1} \frac{1 + a_g x^{\alpha_g}}{a_g + 1}}$$

quality of the fit unchanged by relating $R_{s,g}$ to common R_V

but need different normalization and small-x behavior

- heavy quarks generated radiatively: no parameters
- 3 parameters constrained by charge & momentum conservation

also, fit unchanged if $\epsilon_g = \epsilon_s$

total of 9 parameters per nucleus

$$\xi \in \{\alpha_v, \alpha_s, \alpha_g, \beta_1, \beta_2, \beta_3, a_v, a_s, a_g\}$$

DSSZ: A-dependence

total of 9 parameters per nucleus

$\xi \in \{\alpha_\mathbf{v}, \alpha_\mathbf{s}, \alpha_\mathbf{g}, \beta_\mathbf{1}, \beta_\mathbf{2}, \beta_\mathbf{3}, \mathbf{a_v}, \mathbf{a_s}, \mathbf{a_g}\}$

- A dependence implemented as

$$\xi = \gamma_\xi + \lambda_\xi \mathbf{A}^{\delta_\xi}$$

- fit does not fix all parameters, assume

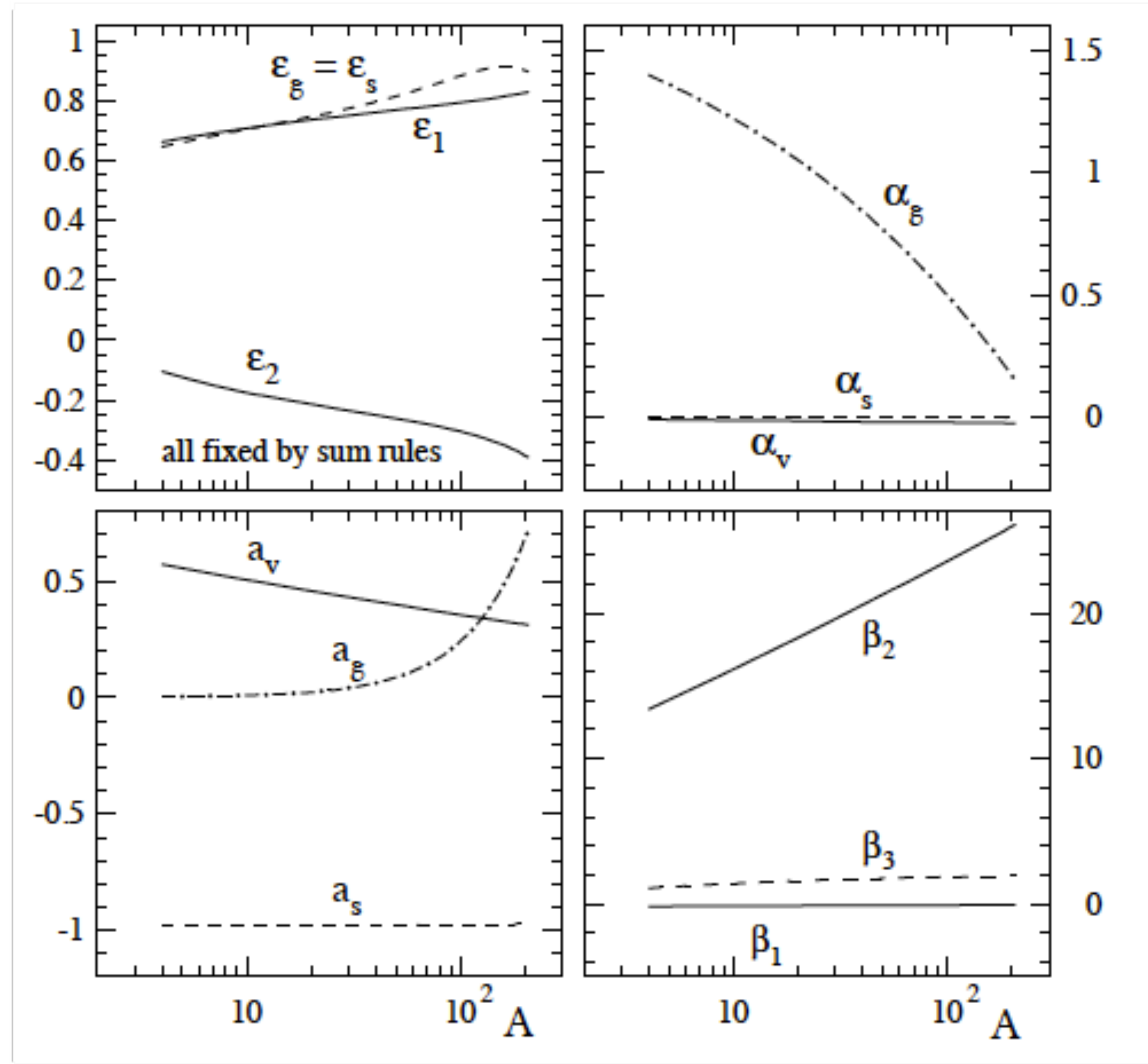
$$\delta_{\mathbf{a_g}} = \delta_{\mathbf{a_s}} \qquad \delta_{\alpha_\mathbf{g}} = \delta_{\alpha_\mathbf{s}}$$

25 free parameters in total

parameter	γ	λ	δ
α_v	-0.256	0.252	-0.017
α_s	0.001	-6.89×10^{-4}	0.286
α_g	1.994	-0.401	0.286
β_1	-5.564	5.36	0.0042
β_2	-59.62	69.01	0.0407
β_3	2.099	-1.878	-0.436
a_v	-0.622	1.302	-0.062
a_s	-0.980	2.33×10^{-6}	1.505
a_g	0.0018	2.35×10^{-4}	1.505

optimum NLO parameters at the input scale

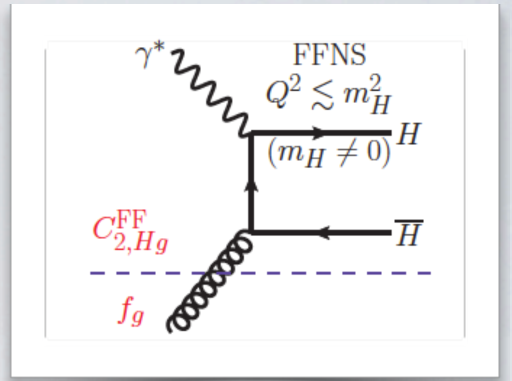
A dependence of fit parameters



DSSZ: heavy flavors

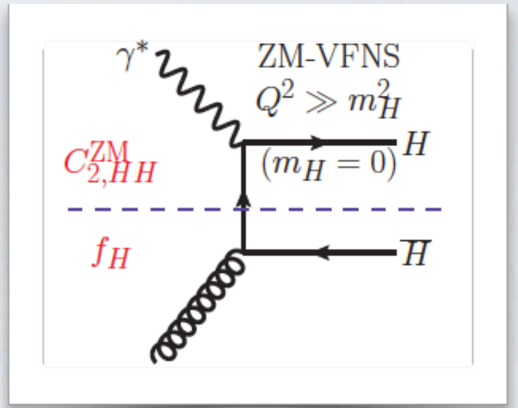
different ways to treat heavy quarks:

$\mathbf{Q \not\gg m_Q}$ ▸ **fixed flavor number scheme** (FFNS)
HQ only produced extrinsically via, e.g., photon-gluon fusion



$\mathbf{Q \ggg m_Q}$ ▸ **zero mass variable flavor number scheme** (ZM-VFNS)
massless HQ above "threshold" Q = m_Q; active in evolution

$\mathbf{Q \gg m_Q}$ ▸ **general mass variable flavor number scheme** (GM-VFNS)
attempt to match massless and massive theories;
needs some matching & interpolating coefficients
details vary in global fits (many prescriptions)



not a priori clear if/where it matters

e.g. HERA data described well in both FFNS and GM-VFNS; ZM-VFNS clearly inadequate

charm production in CC DIS is of special interest

$$\mathbf{W^+ s' \to c} \qquad \mathbf{s' \equiv |V_{cs}|^2 s + |V_{cd}|^2 d}$$

➥ *used to extract strangeness from CC neutrino data in PDF fits*
need to control nuclear corrections for Fe and Pb targets

➥ *we adopt the GM-VFNS as defined in the free proton PDFs of MSTW*
positive impact on quality of our fit to CC DIS data: 26% gain in χ^2

DSSZ: data sets & χ^2

- optimum parameters determined from standard chi-squared optimization

relative normalization or artificial weights for certain data sets

not needed/used in DSSZ analysis

$$\chi^2 \equiv \sum_{\mathbf{i}} \omega_{\mathbf{i}} \frac{(\mathbf{d}\sigma_{\mathbf{i}}^{\mathrm{exp}} - \mathbf{d}\sigma_{\mathbf{i}}^{\mathrm{th}})^2}{\Delta_{\mathbf{i}}^2}$$

uncertainty for each point

DSSZ: add sys + stat in quadrature [+ theor. unc.]

total χ^2 : **1544.7/1579**pts. χ^2/d.o.f : **0.994**

measurement	collaboration	# points	χ^2
F_2^{He}/F_2^D	NMC	17	18.18
	E139	18	2.71
F_2^{Li}/F_2^D	NMC	17	17.35
F_2^{Li}/F_2^D Q^2 dep.	NMC	179	197.36
F_2^{Be}/F_2^D	E139	17	44.17
F_2^{C}/F_2^D	NMC	17	27.85
	E139	7	9.66
	EMC	9	6.41
F_2^{C}/F_2^D Q^2 dep.	NMC	191	201.63
F_2^{Al}/F_2^D	E139	17	13.22
F_2^{Ca}/F_2^D	NMC	16	18.60
	E139	7	12.13
F_2^{Cu}/F_2^D	EMC	19	18.62
F_2^{Fe}/F_2^D	E139	23	34.95
F_2^{Ag}/F_2^D	E139	7	9.71
F_2^{Sn}/F_2^D	EMC	8	16.59
F_2^{Au}/F_2^D	E139	18	10.46
F_2^{C}/F_2^{Li}	NMC	24	33.17
F_2^{Ca}/F_2^{Li}	NMC	24	25.31
F_2^{Be}/F_2^{C}	NMC	15	11.76
F_2^{Al}/F_2^{C}	NMC	15	6.93
F_2^{Ca}/F_2^{C}	NMC	15	7.71
F_2^{Ca}/F_2^{C}	NMC	24	26.09
F_2^{Fe}/F_2^{C}	NMC	15	10.38
F_2^{Sn}/F_2^{C}	NMC	15	4.69
F_2^{Sn}/F_2^{C} Q^2 dep.	NMC	145	102.31
F_2^{Pb}/F_2^{C}	NMC	15	9.57
$F_2^{\nu Fe}$	NuTeV	78	109.65
$F_3^{\nu Fe}$	NuTeV	75	79.78
$F_2^{\nu Fe}$	CDHSW	120	108.20
$F_3^{\nu Fe}$	CDHSW	133	90.57
$F_2^{\nu Pb}$	CHORUS	63	20.42
$F_3^{\nu Pb}$	CHORUS	63	79.58
$d\sigma_{DY}^{C}/d\sigma_{DY}^{D}$	E772	9	9.87
$d\sigma_{DY}^{Ca}/d\sigma_{DY}^{D}$	E772	9	5.38
$d\sigma_{DY}^{Fe}/d\sigma_{DY}^{D}$	E772	9	9.77
$d\sigma_{DY}^{W}/d\sigma_{DY}^{D}$	E772	9	19.29
$d\sigma_{DY}^{Fe}/d\sigma_{DY}^{Be}$	E866	28	20.34
$d\sigma_{DY}^{W}/d\sigma_{DY}^{Be}$	E866	28	26.07
$d\sigma_{\pi^0}^{dAu}/d\sigma_{\pi^0}^{pp}$	PHENIX	20	27.71
$d\sigma_{\pi^0}^{dAu}/d\sigma_{\pi^0}^{pp}$	STAR	11	3.92
$d\sigma_{\pi^\pm}^{dAu}/d\sigma_{\pi^\pm}^{pp}$	STAR	30	36.63
Total		1579	1544.70

NC DIS 897.5/894

CC DIS 488.2/532

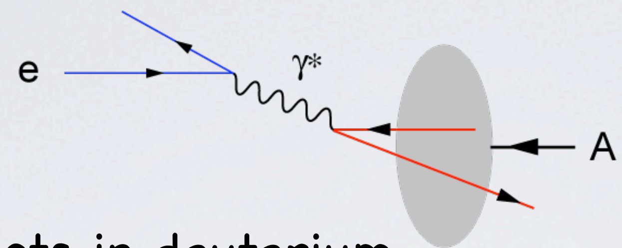
Drell Yan 90.7/92

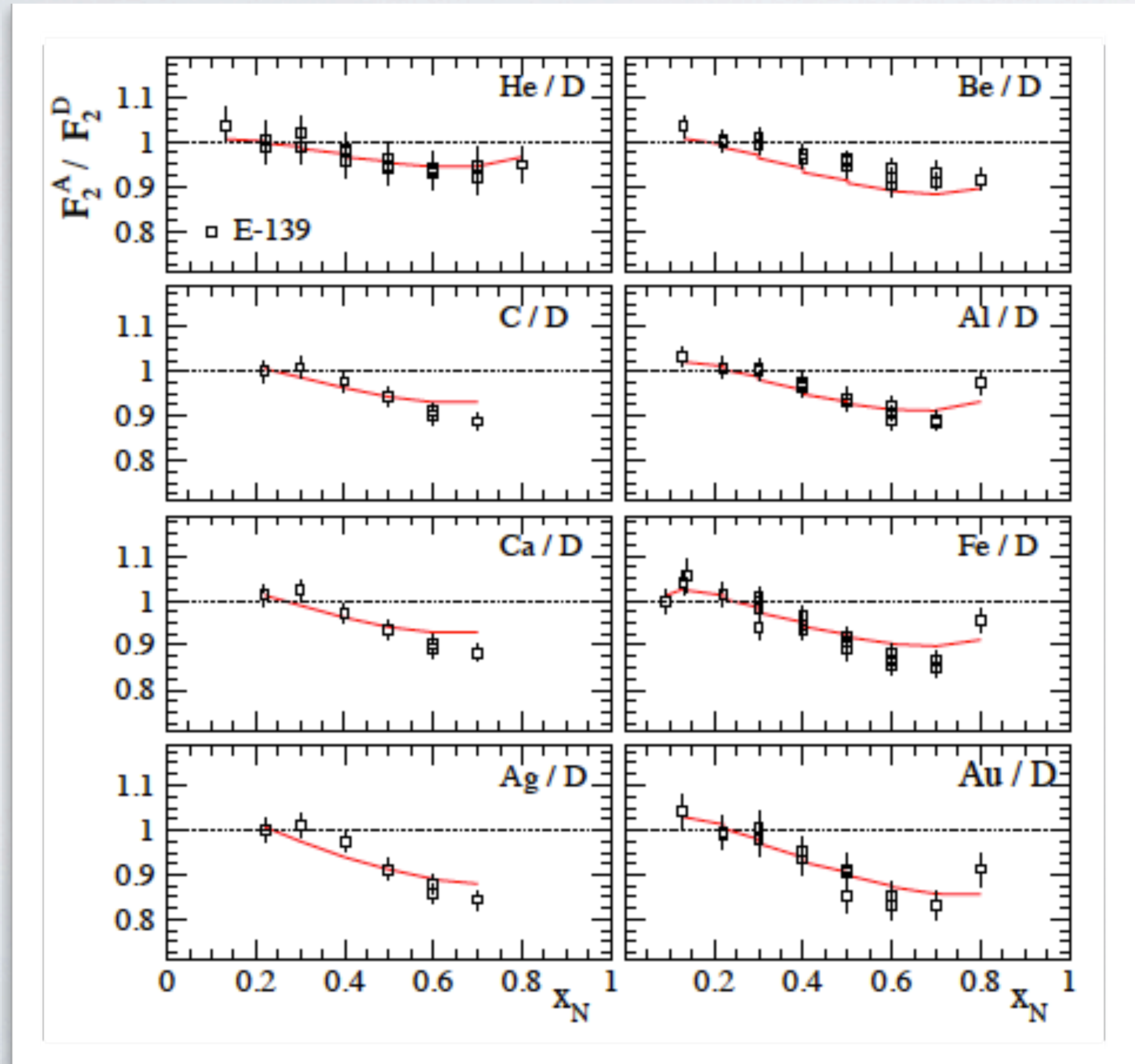
dAu->piX 68.3/61

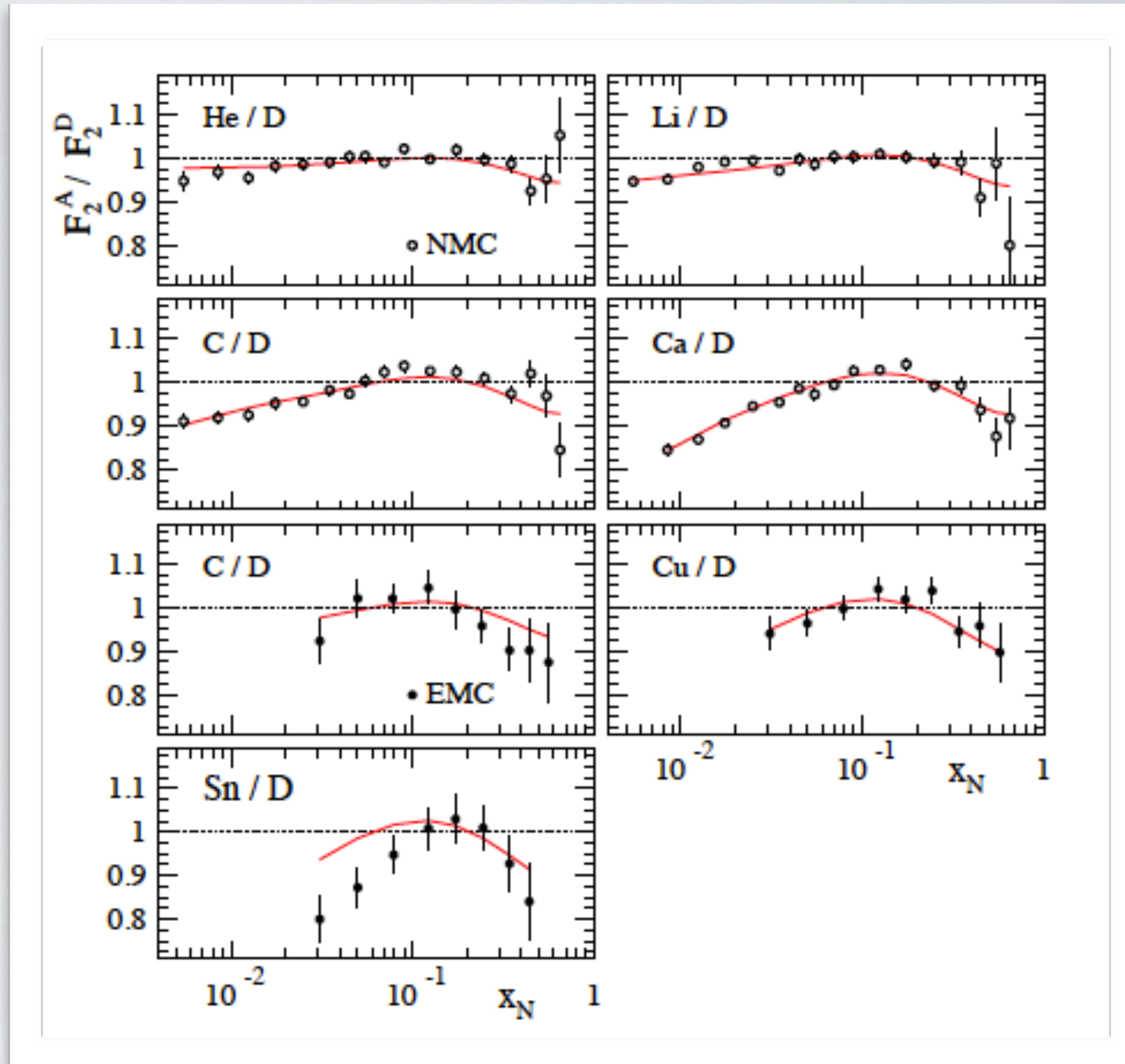
DSSZ: charged lepton DIS data

fit all "classic" EMC, NMC, and E-139 DIS data

- impose cut $Q^2 > 1\,\mathrm{GeV}^2$
- $\chi^2 = 857.5/894\mathrm{pts.}$
- neglect, as usual, nuclear effects in deuterium found to be small in Hirai, Kumano, Nagai







recall

main constraint from DIS data $0.01 \lesssim x \lesssim 0.8$

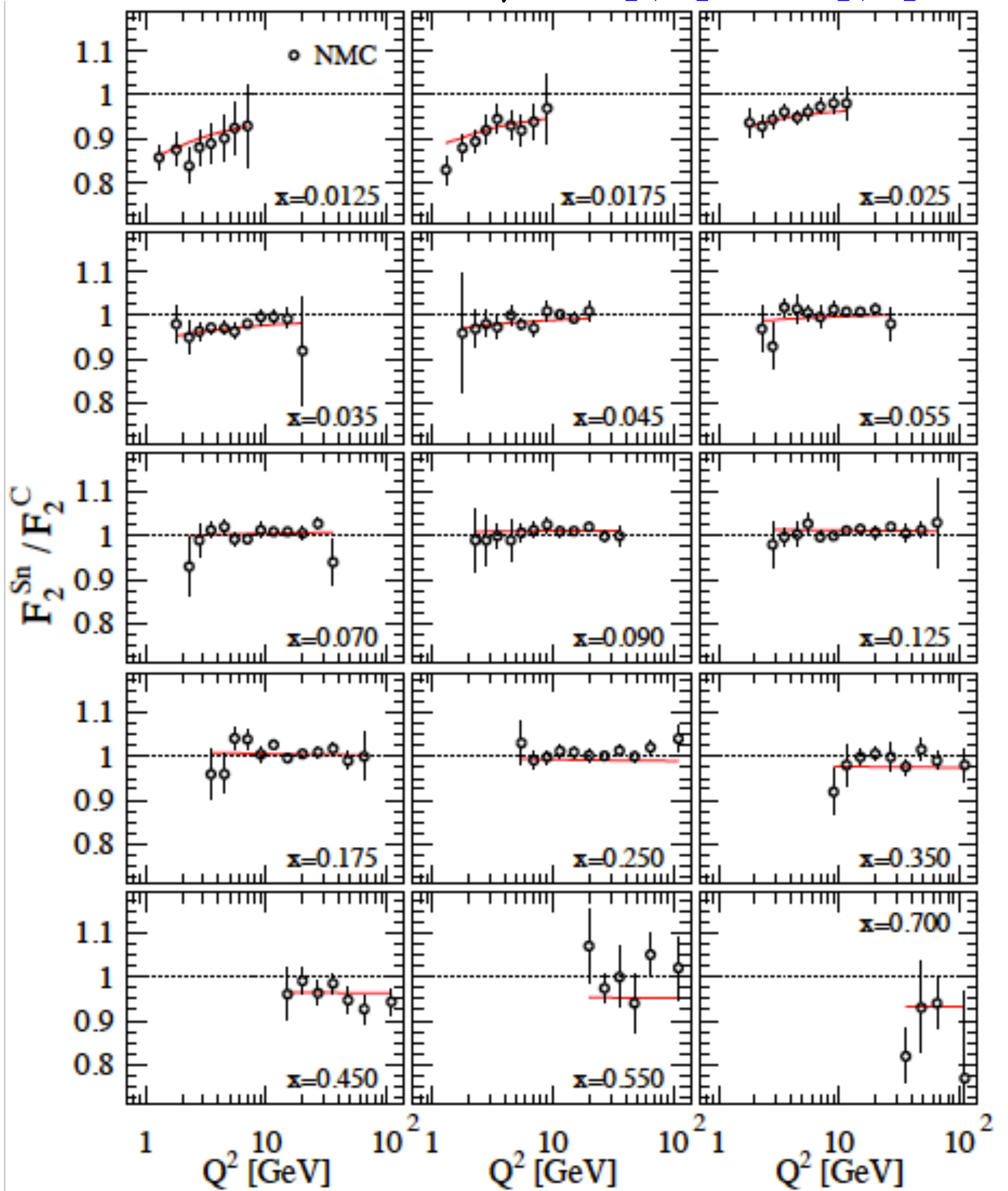
$$F_2^A(N) = x\sum_q e_q^2\Big[\big(q^A(N)+\bar{q}^A(N)\big)\Big(1+\frac{\alpha_s}{2\pi}C_2^q(N)\Big) + \frac{\alpha_s}{2\pi}C_2^g(N)\,g^A(N)\Big]$$

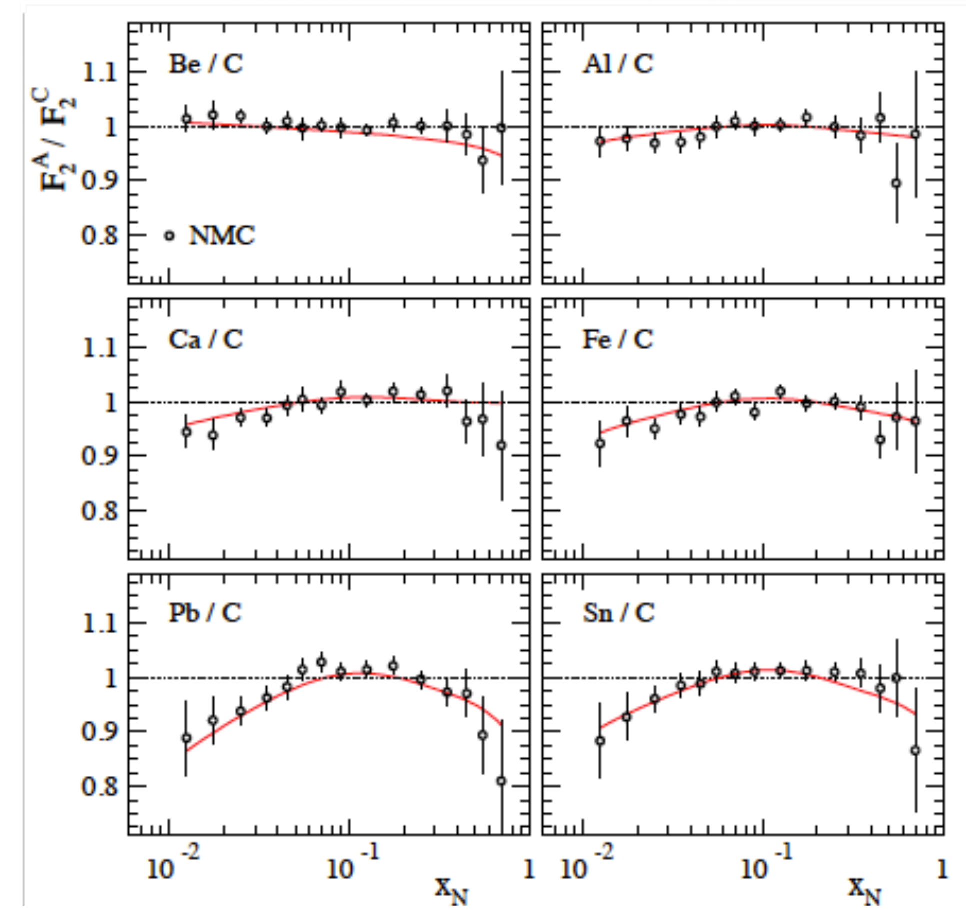
weak indirect constraint from scale evolution

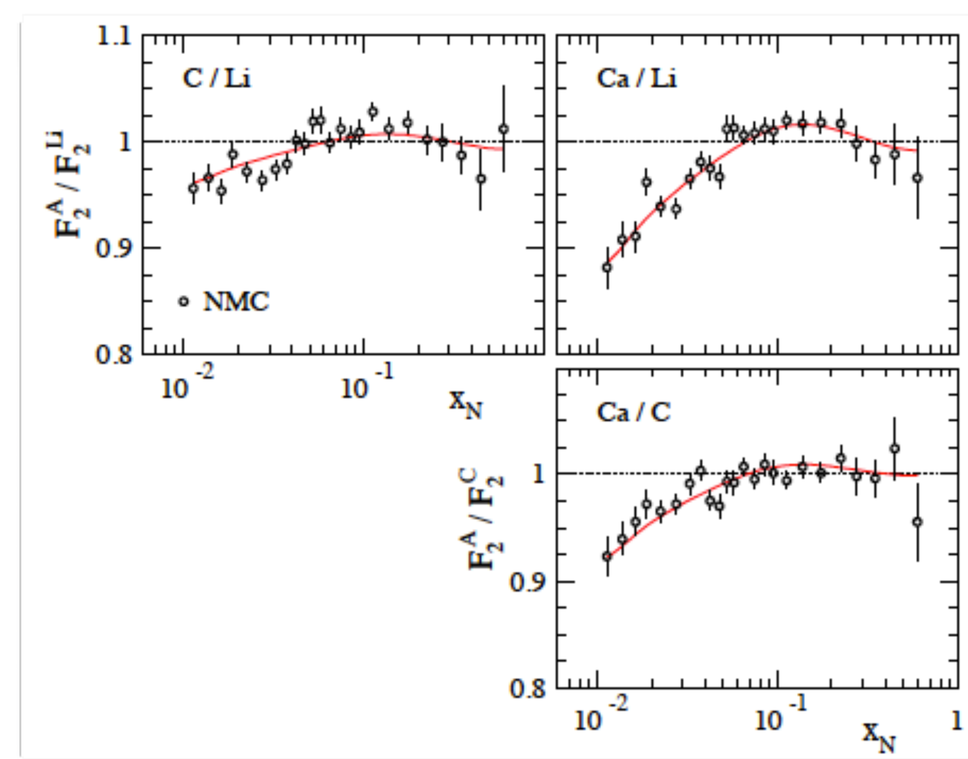
DSSZ: charged lepton DIS data

there is more ... no surprises though

similarly for F_2^{Li}/F_2^{D} and F_2^{C}/F_2^{D}



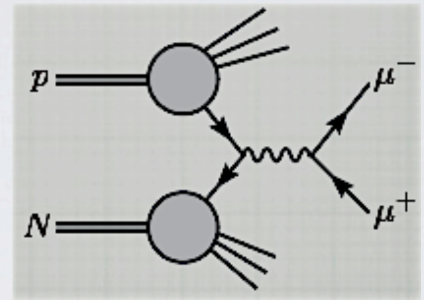




DSSZ: Drell-Yan dimuon data

fit all E772 and E866 DY pA data

- di-muons have inv. mass M > 4 GeV (sets scale)
- $\chi^2 = \mathbf{90.7/92}$pts.



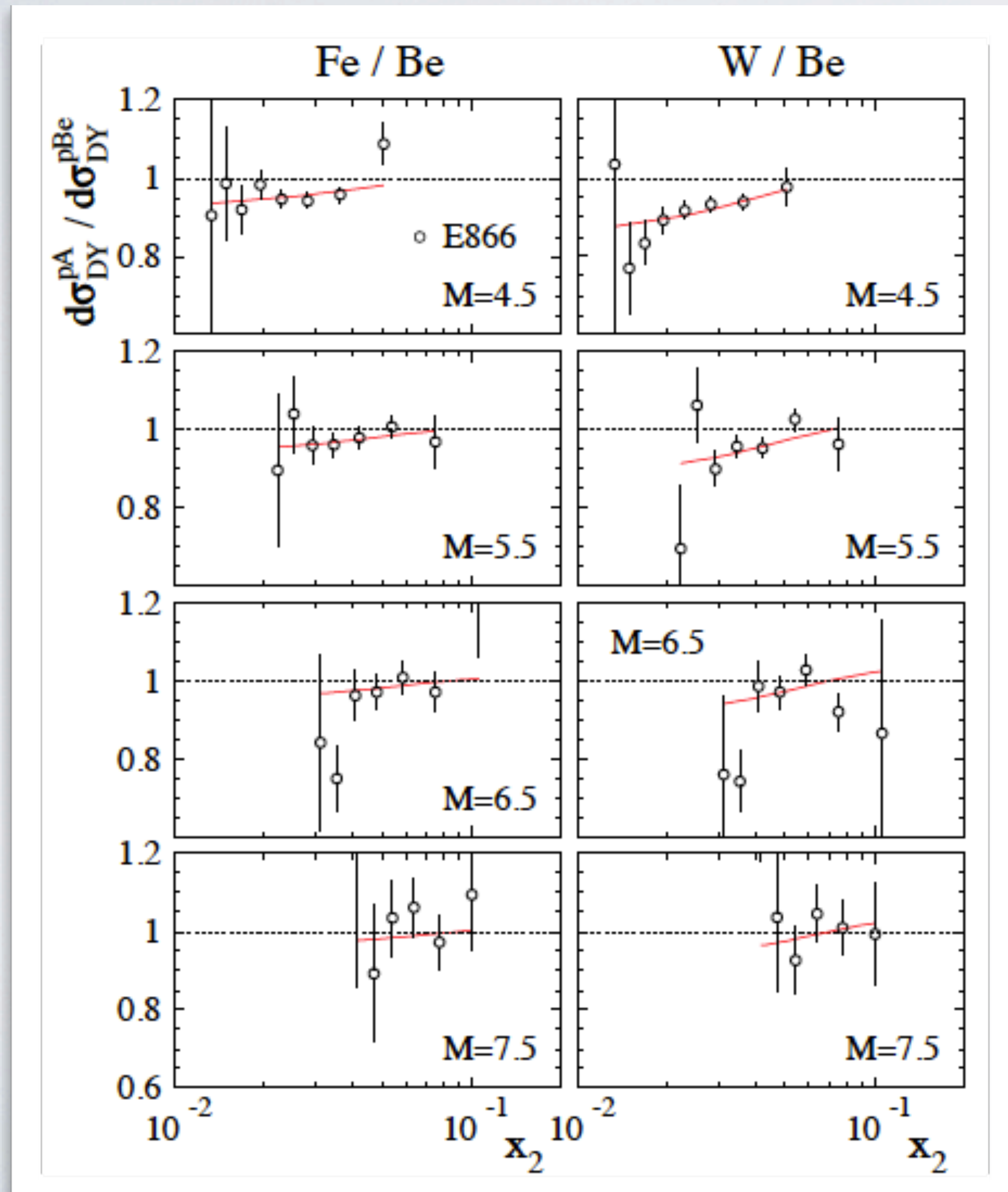
$$\mathbf{x_{1,2} = \sqrt{M^2/s}\, e^{\pm y}}$$

DY data mainly help to disentangle val/sea quarks

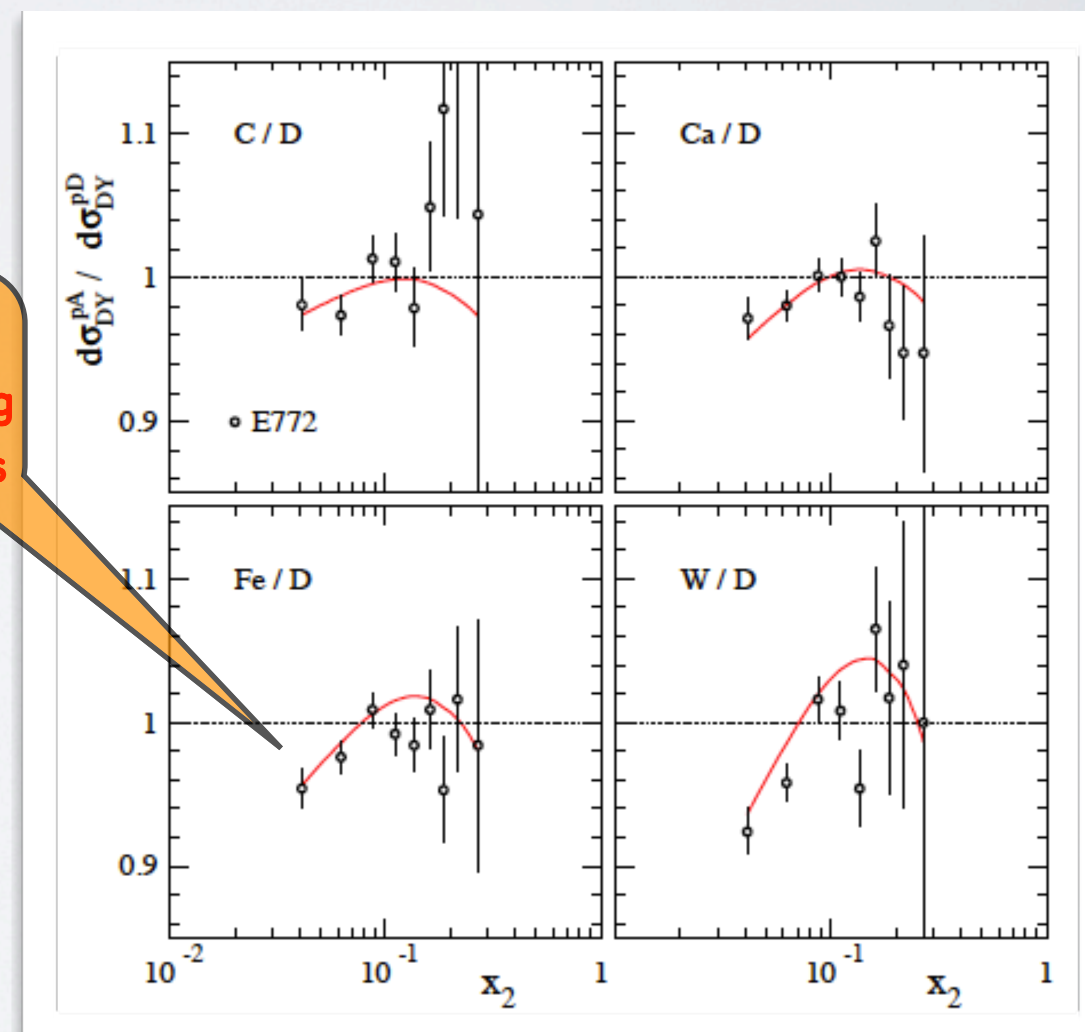
gluons through evolution

$$\mathbf{\frac{d^2\sigma}{dMdy} = \frac{4\pi\alpha^2}{9M^3} \sum_{ij} \int dx_1 dx_2\, f_i^p(x_1)\, f_j^A(x_2)\, \frac{d\hat{\sigma}_{ij}}{dMdy}}$$

$$\mathbf{x_2 \in [0.01, 0.2]}$$



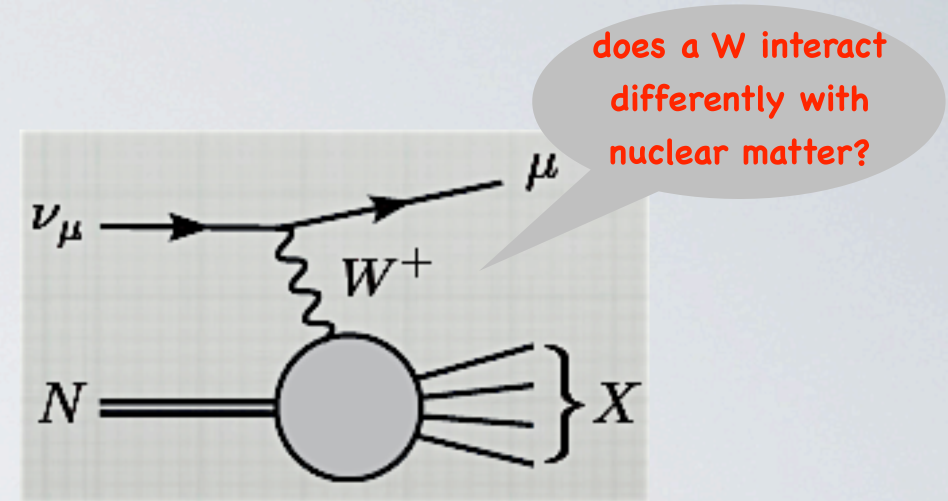
"evidence" for shadowing of sea quarks



DSSZ: cc neutrino DIS data

fit CDHSW, NuTeV, and CHORUS str. fct. data

substantial interest:



- nCTEQ claim of "**factorization breaking**" for nPDFs
- neutrino data are a vital constraint on strangeness (and help to separate quark flavors) in proton PDF fits

$$\frac{d^2\sigma^{\nu A,\bar\nu A}}{dxdy} \simeq xy^2 F_1^{\nu A,\bar\nu A} + (1-y) F_2^{\nu A,\bar\nu A} \pm xy(1-\frac{y}{2}) F_3^{\nu A,\bar\nu A}$$

- CC DIS data probe different combinations of up-/down-type quarks than charged-lepton DIS
- neutrino and antineutrino beams probe 4 different structure functions

$$F_2^{\nu A}(x_N) \simeq x_N[\bar u^A + \bar c^A + d^A + s^A](x_N)$$

$$F_2^{\bar\nu A}(x_N) \simeq x_N[u^A + c^A + \bar d^A + \bar s^A](x_N)$$

$$F_3^{\nu A}(x_N) \simeq [-(\bar u^A + \bar c^A) + d^A + s^A](x_N)$$

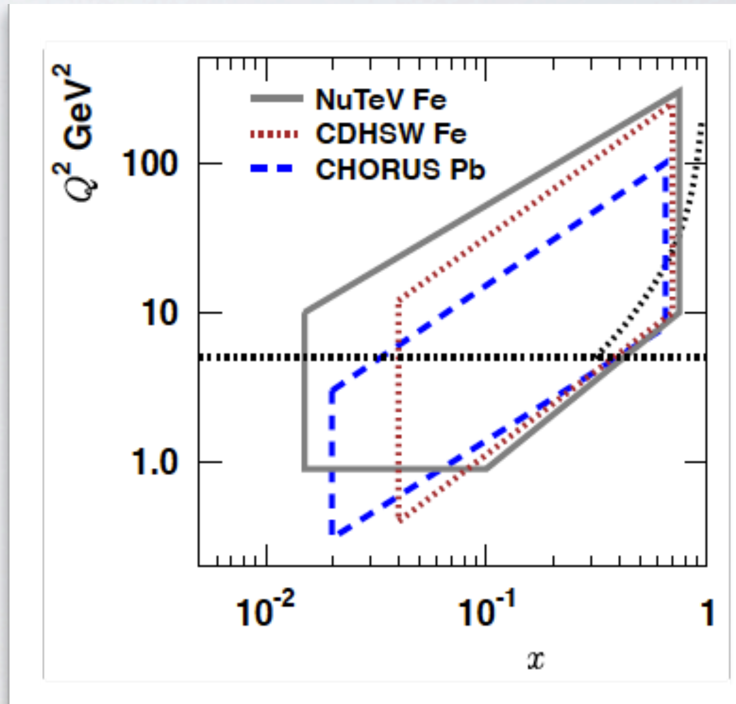
$$F_3^{\bar\nu A}(x_N) \simeq [u^A + c^A - (\bar d^A + \bar s^A)](x_N)$$

potential tension with what we have learned from NC DIS

- experiments extract (under certain assumptions)

$$F_{2,3} \equiv (F_{2,3}^{\nu A} + F_{2,3}^{\bar\nu A})/2 \longrightarrow$$

- F_2 probes total quark singlet
- F_3 probes sum of valence PDFs

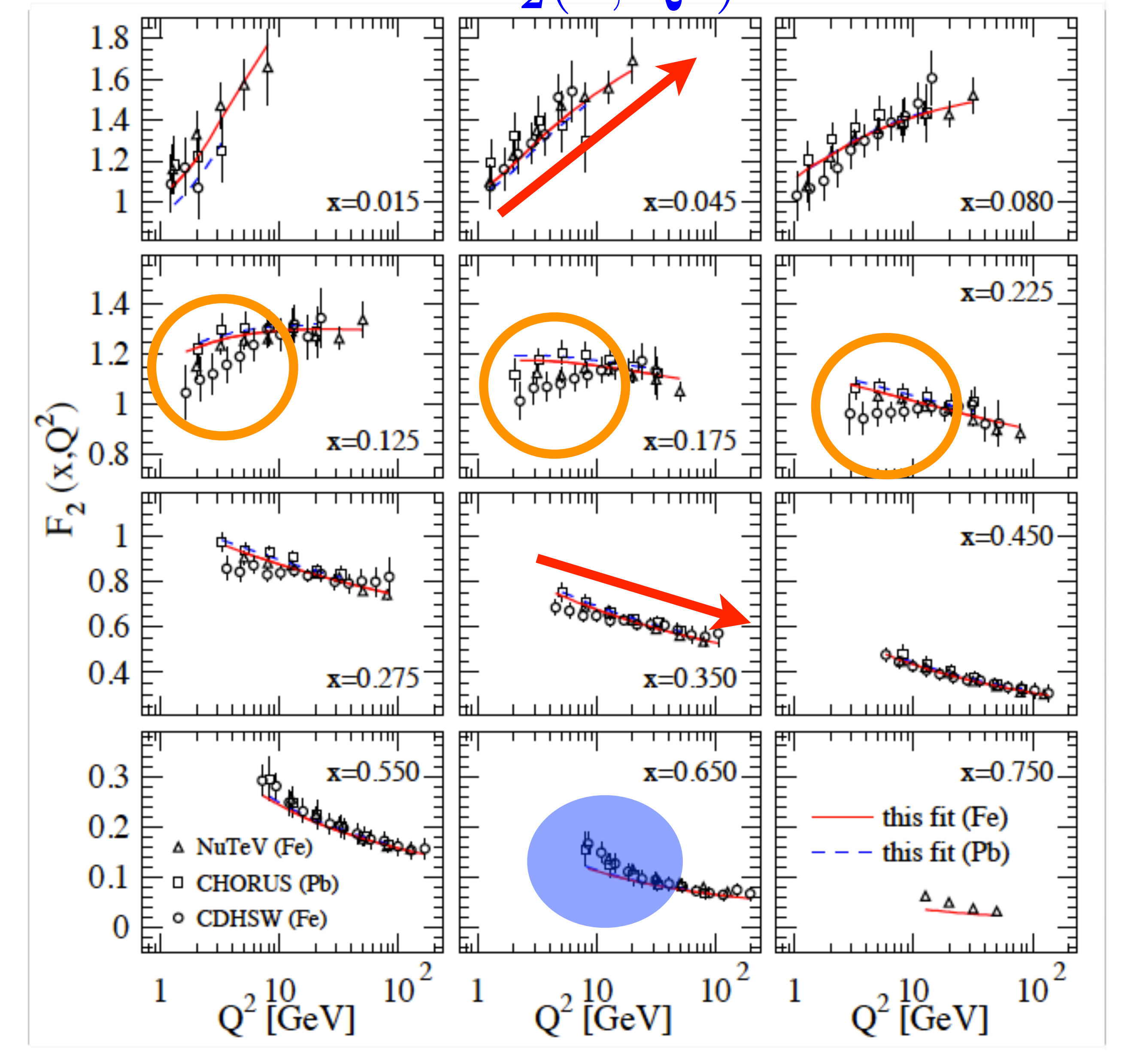


kinematics overlaps with charged lepton DIS data

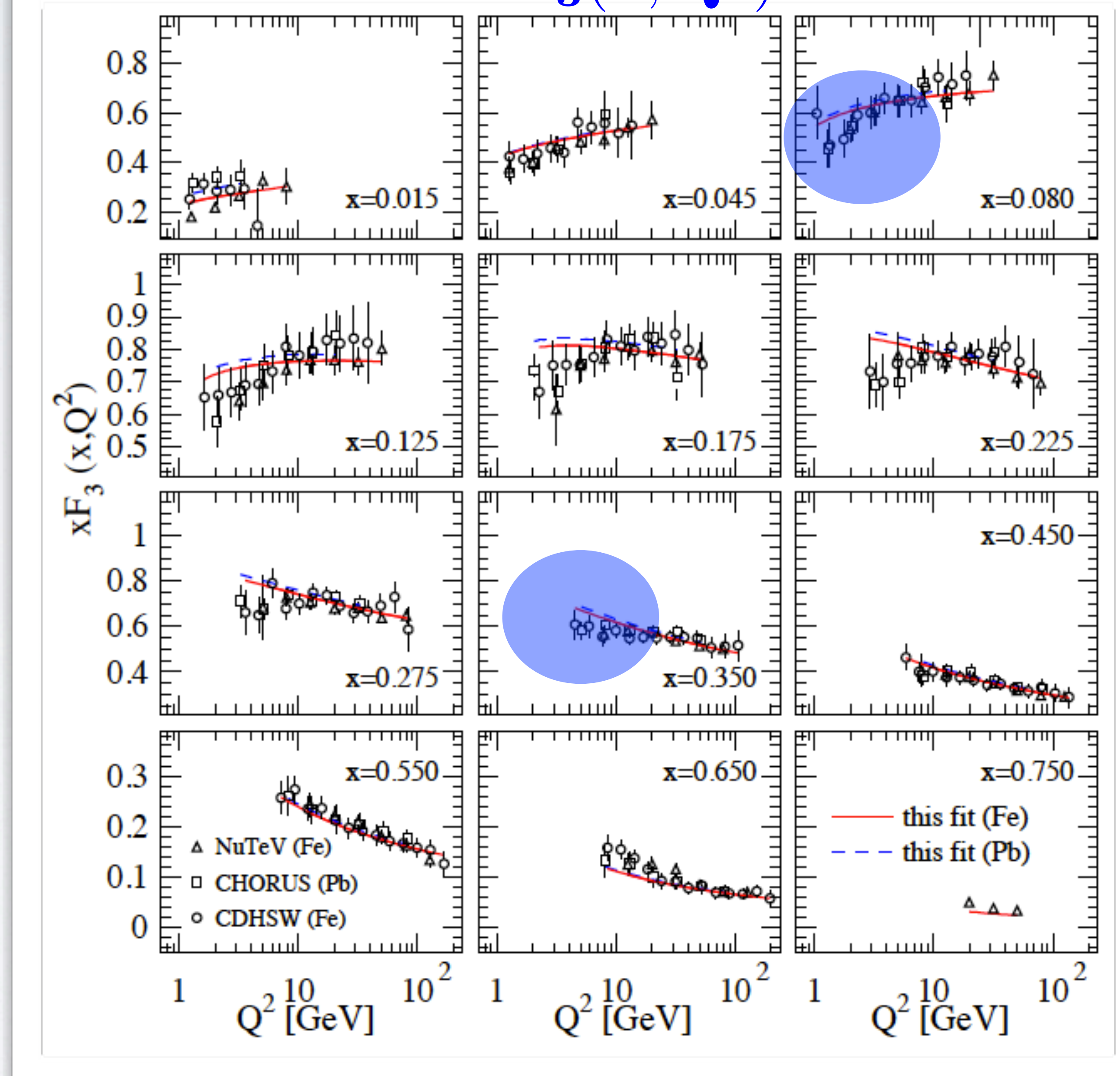
DSSZ: cc neutrino DIS data

find: data remarkably well reproduced by fit $\chi^2 = 488.2/532\text{pts.}$

$\mathbf{F_2(x, Q^2)}$



$\mathbf{xF_3(x, Q^2)}$



- absolute cross sections rather than ratios -> more sensitive to set of proton PDF in R_i^A (incl. as theor. uncertainty)
- data feature typical pattern of scaling violations
- slope of CDHSW data does not match with other data

some mild tensions

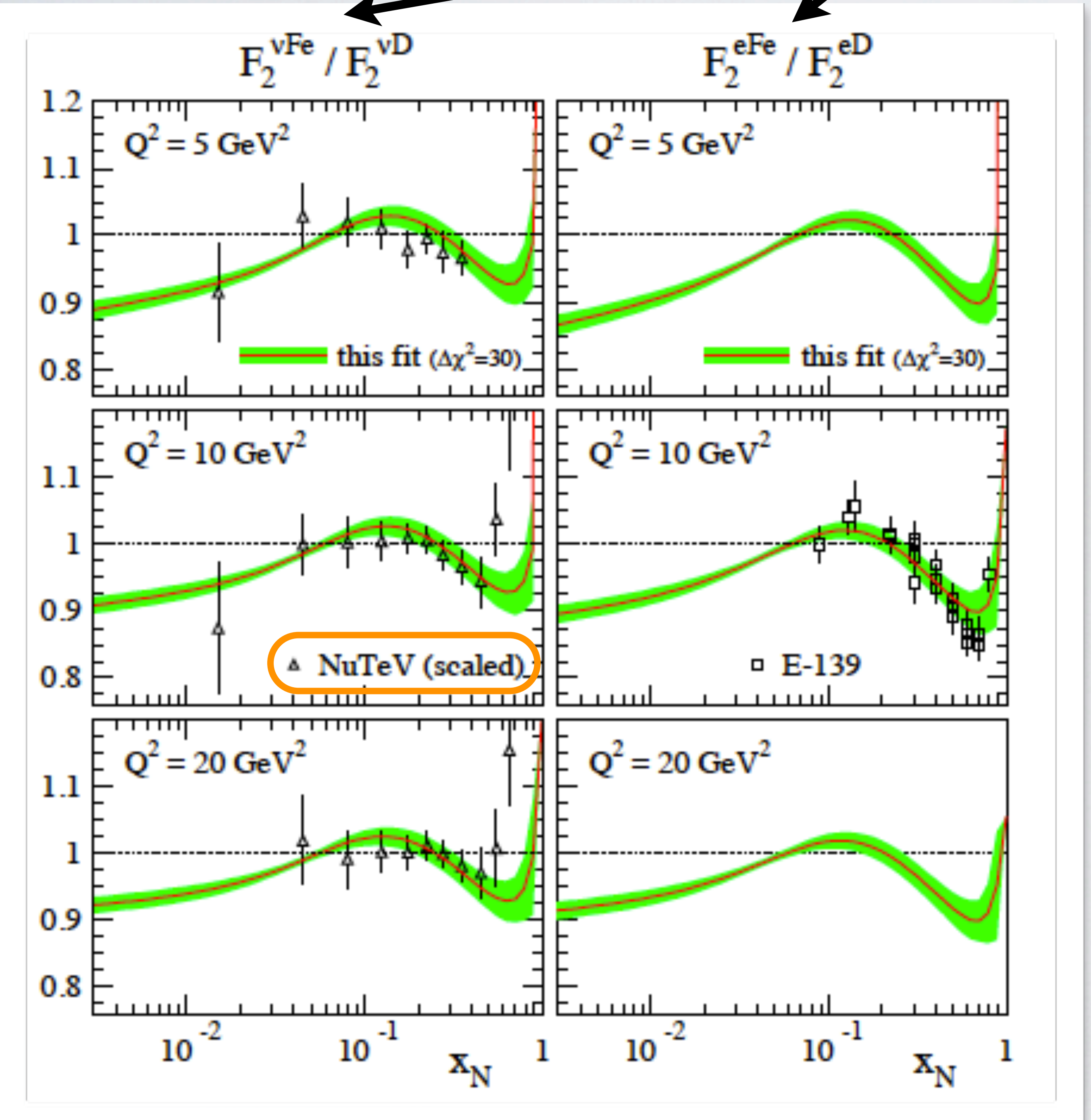
often with CDHSW data

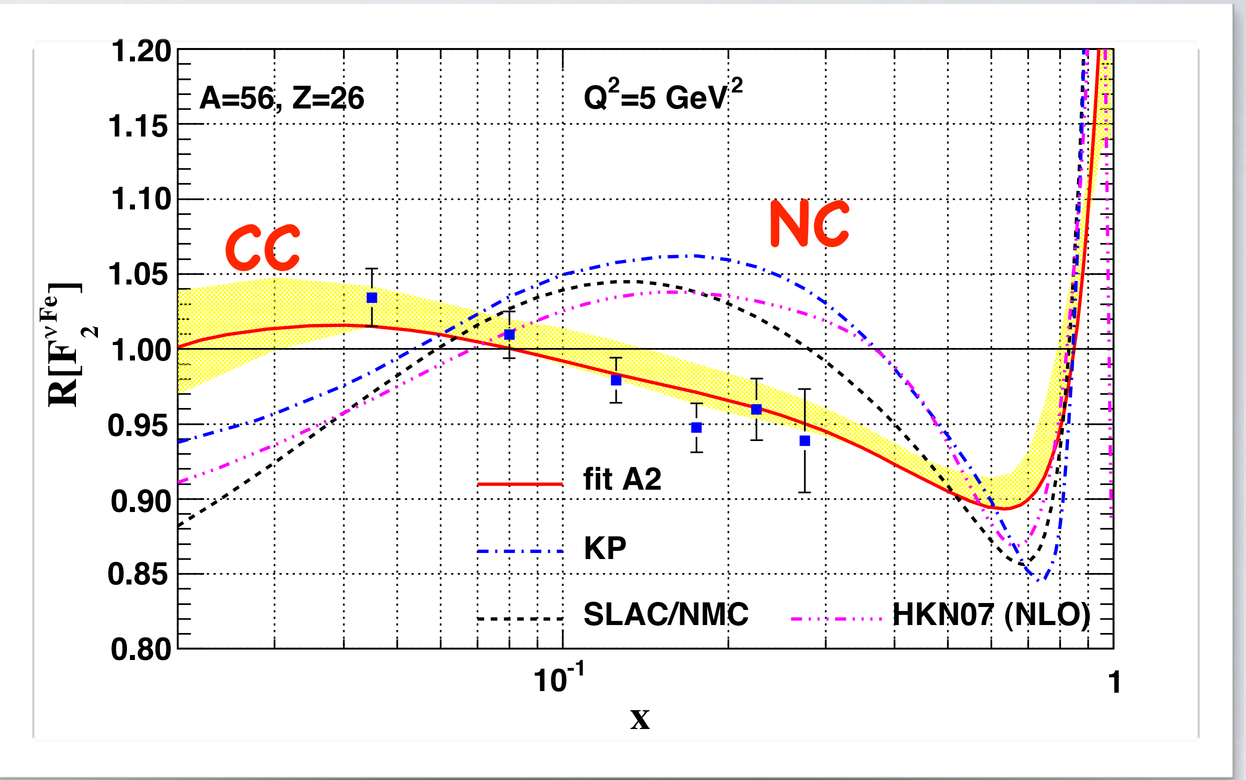
DSSZ: cc neutrino DIS data

no indication for factorization breaking

at variance with nCTEQ result

find same pattern of nuclear effects for CC and NC DIS





- "theoretical data": $\mathbf{F_2^{\nu D}}$ not measured
- nCTEQ fits to cross sections not str. fcts.
- also EPS finds compatible nuclear effects

  (no re-fit including CC DIS yet)

DSSZ: pion production dAu

most difficult probe to analyze (yet, perhaps one of the most interesting ones)

$$\mathbf{d\sigma^{A}_{dA\to\pi X} = \sum_{ijk} f_i^d \otimes f_j^A \otimes d\hat{\sigma}_{ij\to kX} \otimes D_k^{A,\pi}}$$

free proton PDF "known"

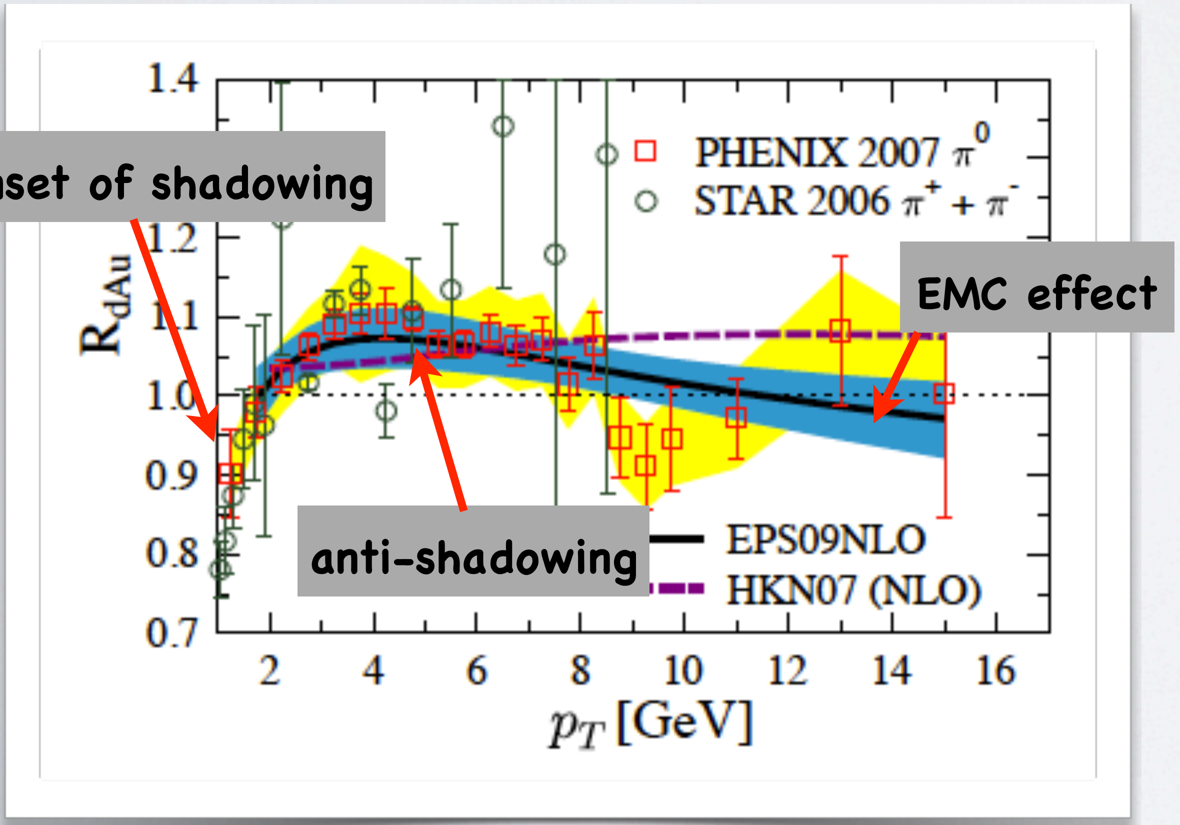
wanted

known to NLO
many contributing subprocesses

fragmentation functions
fairly well known for pions
but what about possible nuclear modifications?
can have an impact even if small

?

mid-rapidity neutral pion data from PHENIX and STAR first analyzed in EPS fit



- fit to min. bias ratio $\mathbf{R^{\pi}_{dAu} = \frac{\frac{1}{2A} d^2\sigma_{dAu}/dp_T dy}{d^2\sigma_{pp}/dp_T/dy}}$
- use up-to-date vacuum fragmentation functions
  DSS: de Florian, R.S., Stratmann - include RHIC pp data
- find BIG impact on gluon nPDF

potential caveat: need to assign large weight to dAu data in fit

DSSZ: pion production dAu

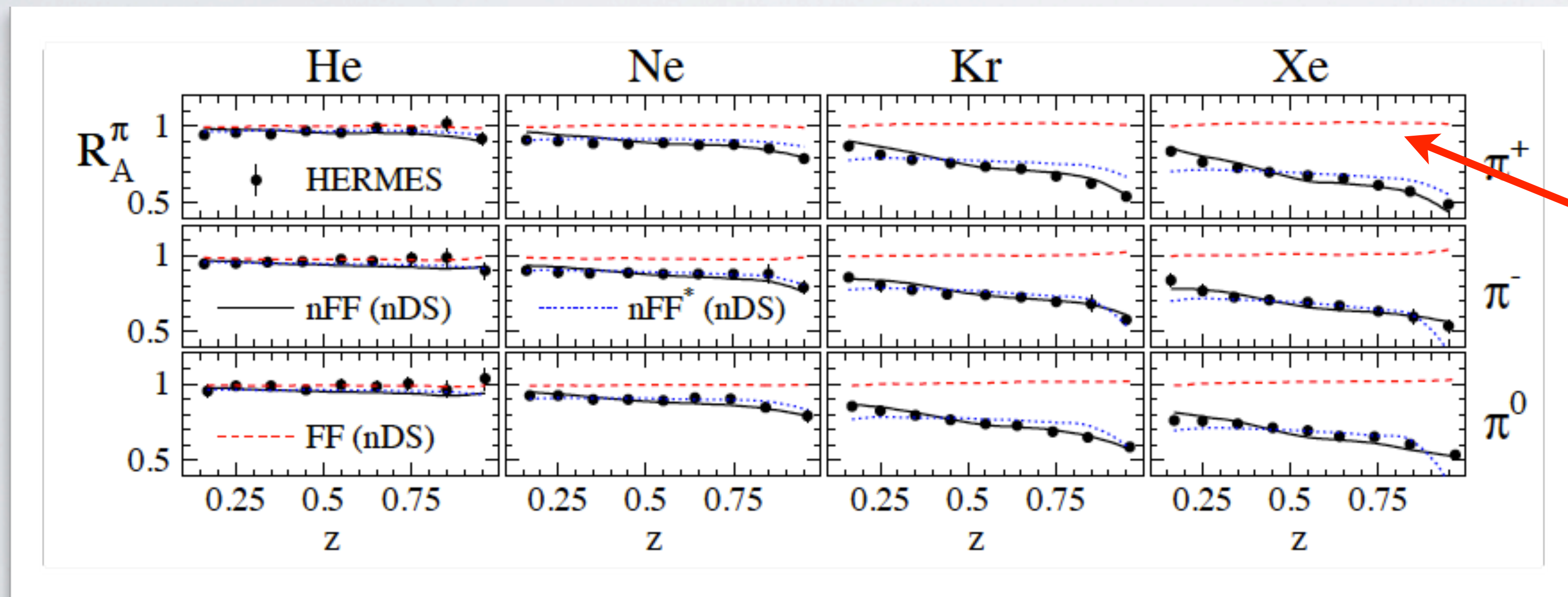
what is different in DSSZ analysis

✓ more data, including also charged pions from STAR

✓ no artificially large weight w.r.t. other data sets

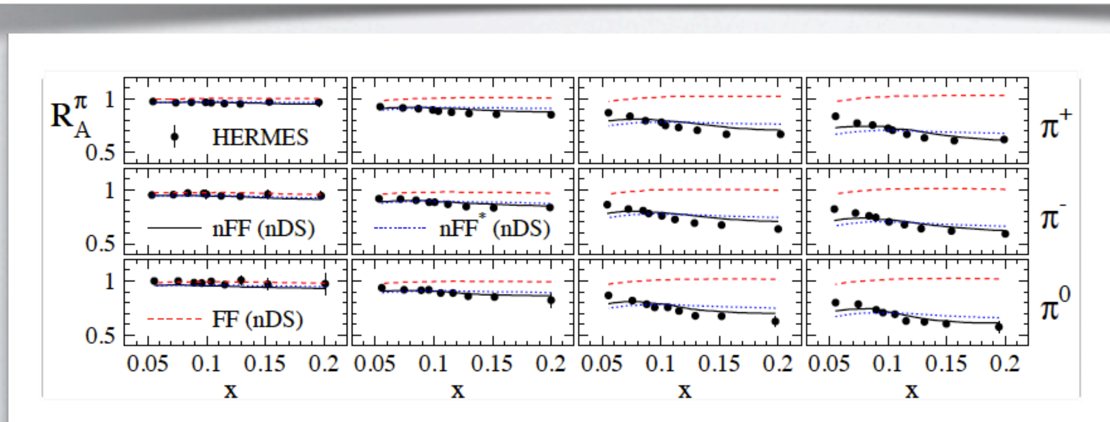
✓ try to estimate impact of modifications in hadronization

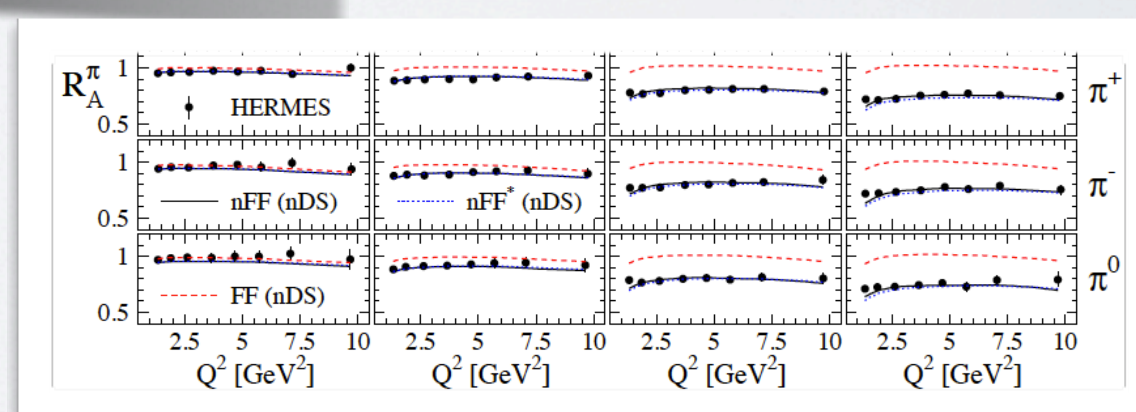
fragmentation in a medium - what is known ?



- effects known to be large in eA
- cannot be described as an initial-state effect (= nPDFs)
- hadron attenuation increases with A and z (rather flat in x and Q^2)

HERMES





DSSZ: nFFs

how to model fragmentation in a medium ?

bold attempt: extend FFs to medium modified FFs ("in the background of a nucleus A")

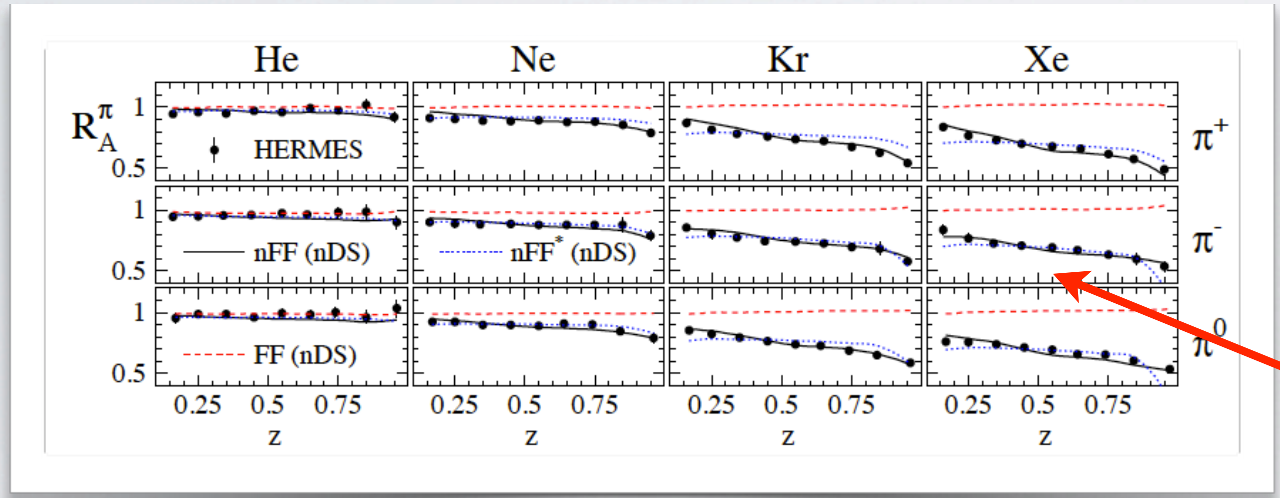
R.S, Stratmann, Zurita
0912.1311

choose convolution ansatz to modify vacuum FFs

DSS vacuum FFs

$$D^H_{i/A}(z, Q_0) = \int_z^1 \frac{dy}{y} W_i(y, A)\, D^H_i(\frac{z}{y}, Q_0)$$

from fit to HERMES and RHIC dAu pion data



works well

Experiment	A	H	Data type	Data points	χ^2
HERMES [6]	He,Ne,Kr,Xe	π^+	z	36	39.3
		π^-	z	36	23.0
		π^0	z	36	27.4
		π^+	x	36	69.4
		π^-	x	36	55.4
		π^0	x	36	49.7
		π^+	Q^2	32	21.0
		π^-	Q^2	32	27.1
		π^0	Q^2	32	34.7
PHENIX [14]	Au	π^0	p_T	22	13.7
STAR (prel.) [16]	Au	π^0	p_T	13	12.8
STAR [15]	Au	$\pi^\pm$	p_T	34	22.5
Total				381	396.0

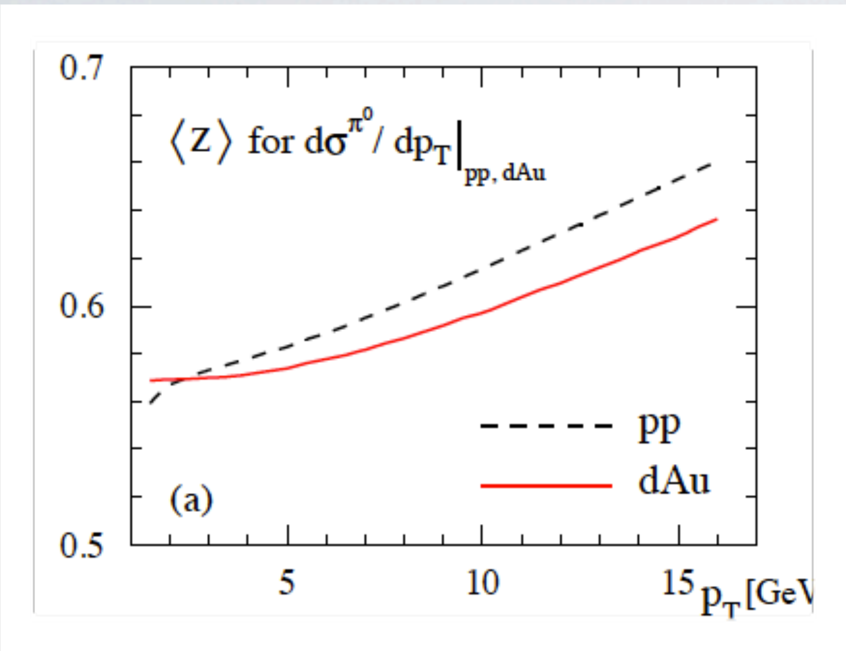
find:

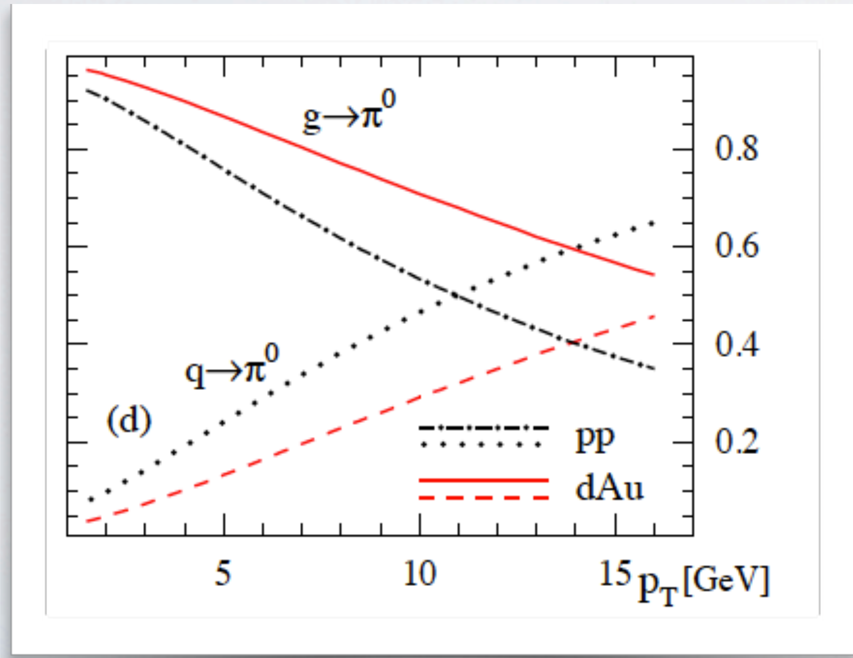
- suppressed quark -> pion fragmentation (incr. with A)
- mildly enhanced gluon fragmentation around z=0.5

use both DSS vacuum and effective nuclear FFs in DSSZ nPDF analysis

DSSZ: mid rapidity (again)

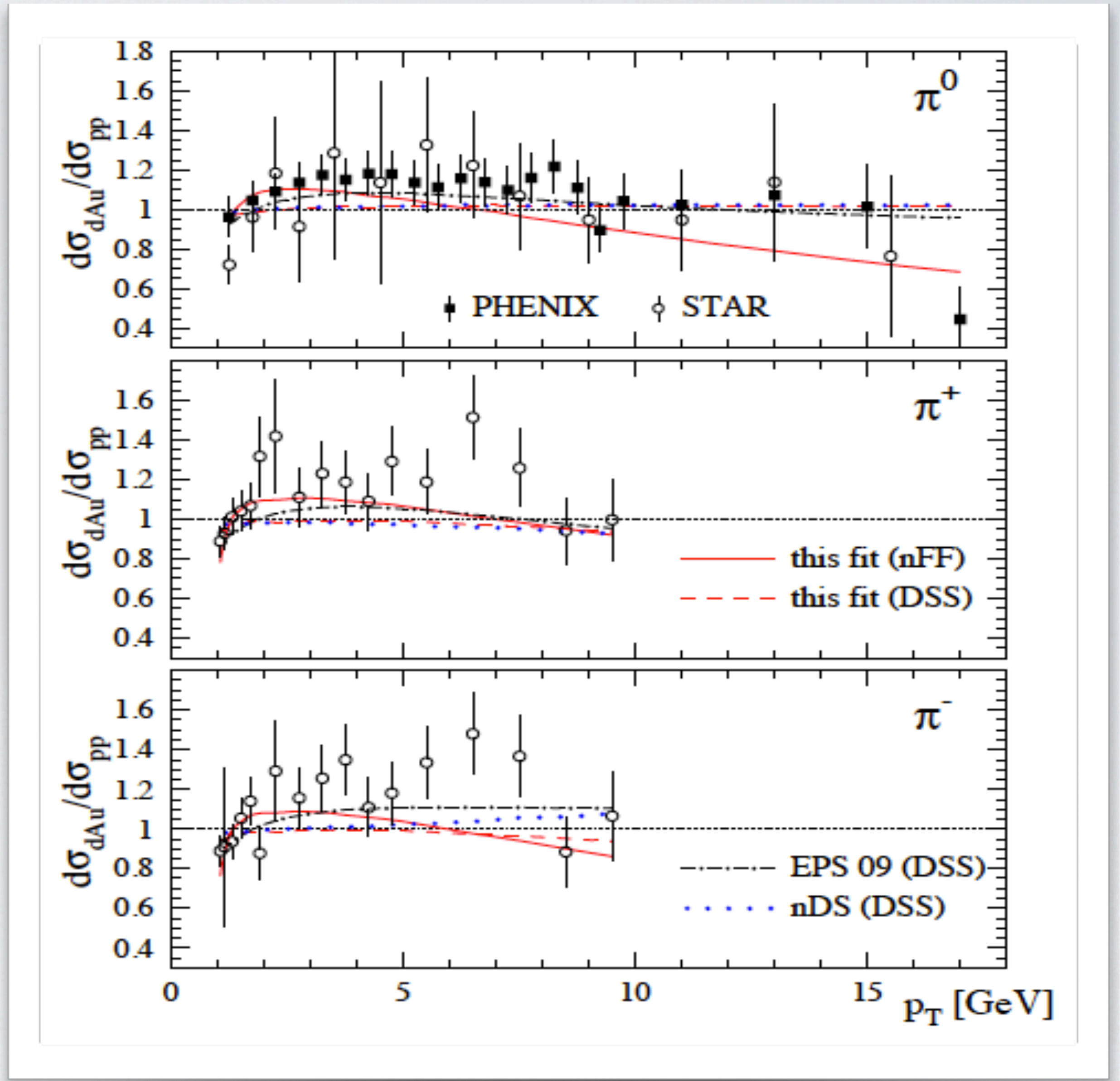
at RHIC (mid rapidity) we probe large z
and mostly pions from gluons





R.S. Stratmann, Zurita 0912.1311

result of our nPDF fit



- good fit within large exp. uncertainties
- choice of FF has some impact (but not too much)

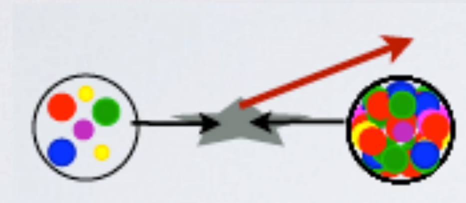
$$\chi^2 : \mathbf{68.3}\,(\mathrm{nFF}) \rightarrow \mathbf{83.6}\,(\mathrm{DSS})$$

- unlike EPS fit, limited impact on gluon (no weight factor)

DSSZ: forward rapidity

why interesting

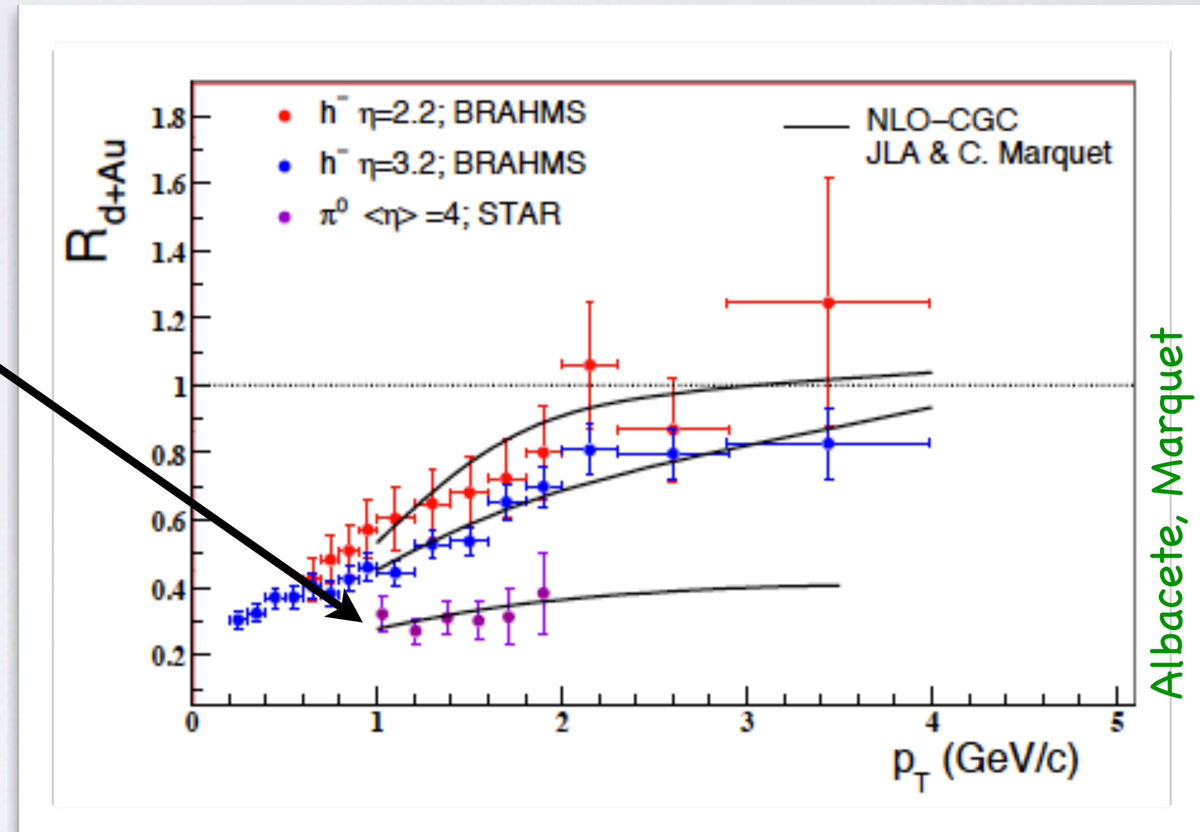
- allows to access smaller x in nucleus
- gets one closer to the region where one expects saturation effects



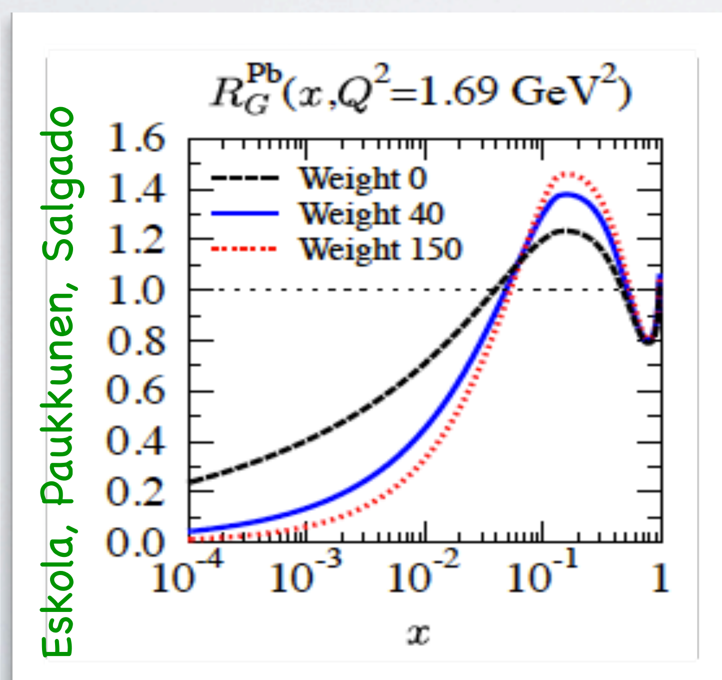
$$\mathbf{x_{1,2} \simeq \frac{p_T}{\sqrt{s}}\, e^{\pm y}}$$

data indicate strong suppression of gluons at small x and low scales

forward suppression well described within **non-linear rcBK evolution** (CGC)

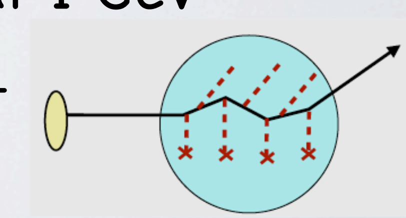


what does it take to describe it with nPDFs



- need humongous shadowing at a scale of about 1 GeV

⚠ could be much less if final-state effects are relevant
advocated by Frankfurt, Strikman; Kopeliovich; ...



DSSZ: AA collisions *no, thanks*

many observables of interest involve

small p_T, global properties, centrality dependence, ...

- **nPDFs are collinear objects**
  there is no impact parameter or other geometrical dependence

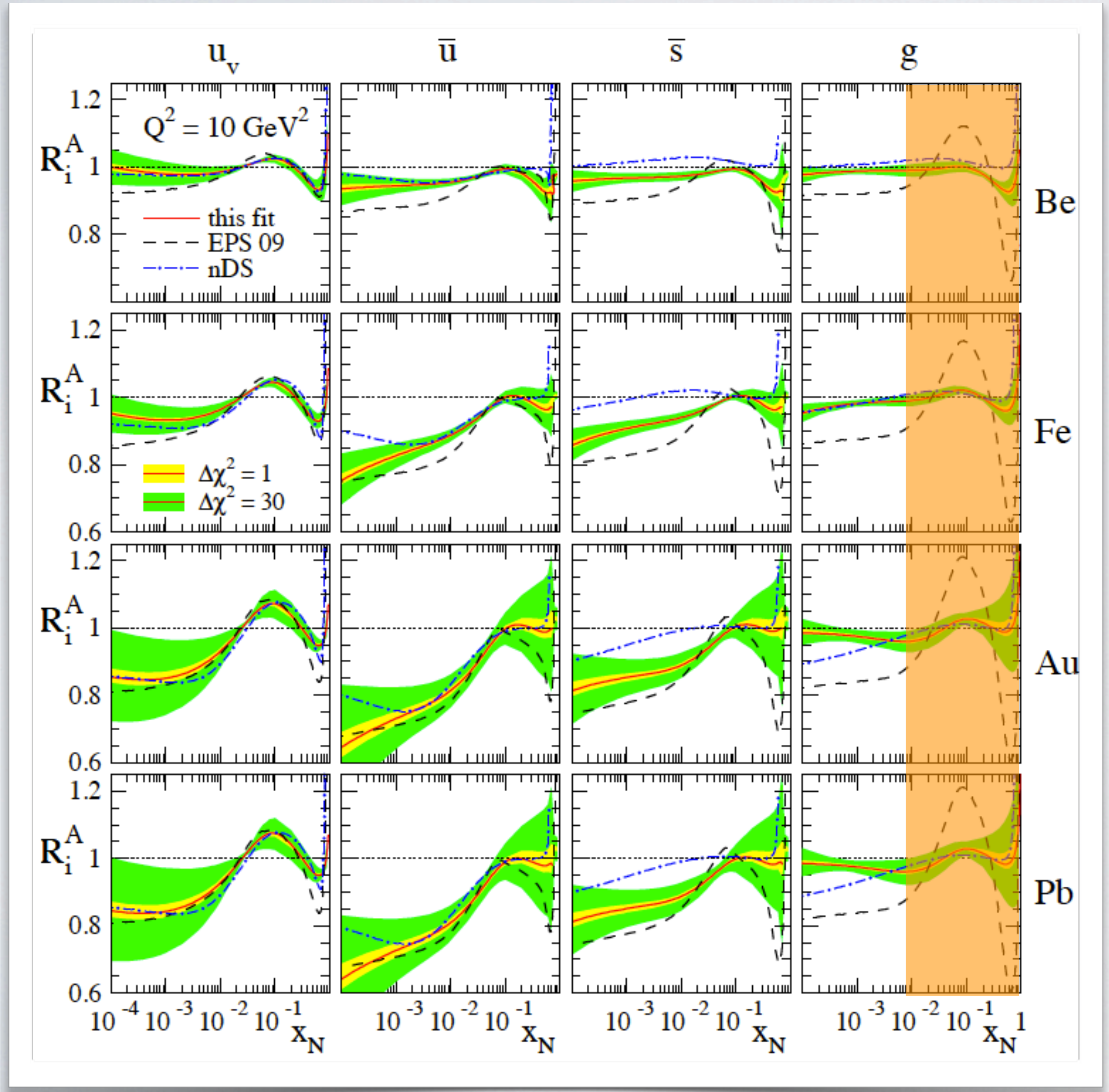
- **many observables in AA have no "hard scale"**
  not amenable to pQCD calculations in standard factorizations

- **assuming factorization in AA is a stretch**
  there might be some hard probes where things work out though

we do not touch AA data for the time being
nPDFs should be determined from probes in eA or pA
preferentially electromagnetic ones (free of hadronization issues)

DSSZ: nPDFs

A dependence at $Q^2 = 10\ \mathrm{GeV}^2$



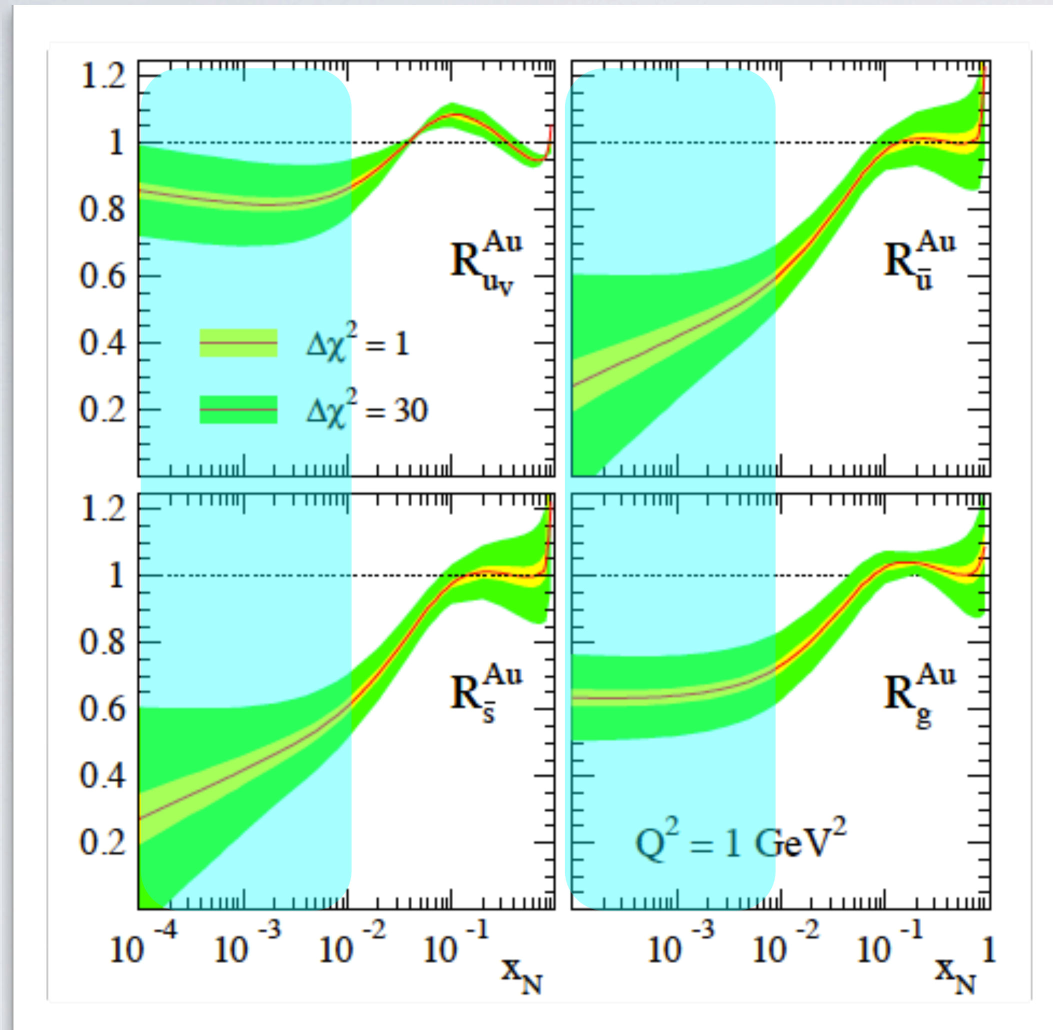
- nuclear modifications increase with A
- good agreement with previous fits for $\mathbf{R^A_{u_V}}$ and $\mathbf{R^A_{\bar{u}}}$
- less so for $\mathbf{R^A_{\bar{s}}}$

  due to recent changes in free proton PDFs
- **MUCH less anti-shadowing and EMC effect than for EPS gluon**

  driven by the way dAu data are analyzed

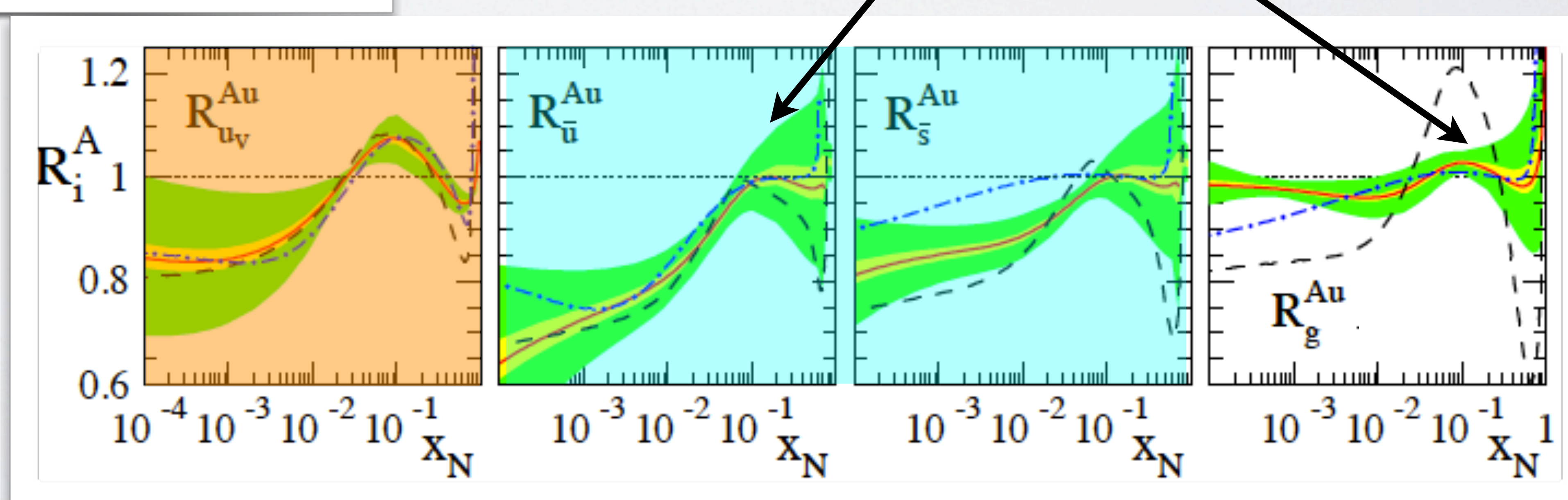
DSSZ: nPDFs & uncertainties

uncertainties at input scale of 1 GeV (for gold nucleus)

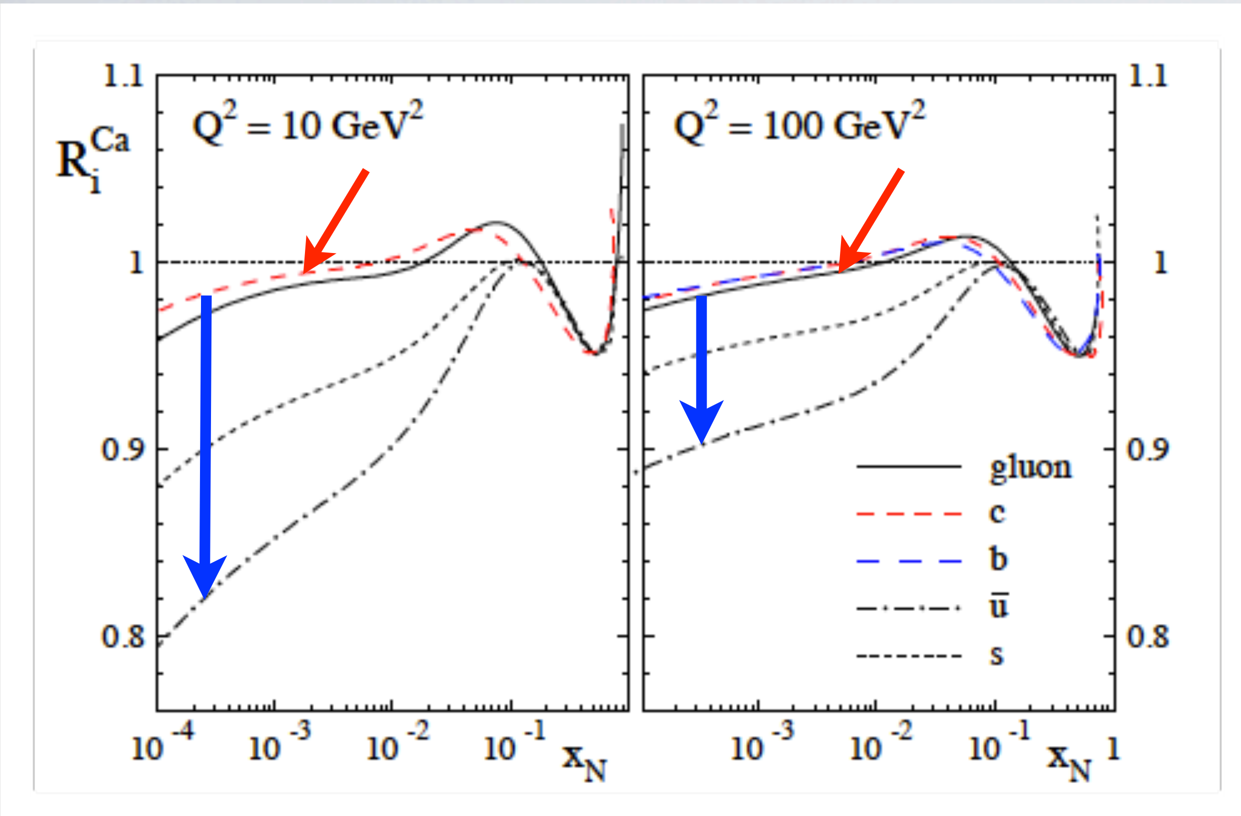


- **uncertainties below 0.01** merely reflect extrapolation of chosen functional form
  not constrained by any data
- nuclear modifications quickly diminish under evolution
- evolution imprints different nuclear effects on individual quark flavors
  recall: we start with $\mathbf{R^A_{\bar{u}} = R^A_{\bar{d}} = R^A_{\bar{s}}}$
- $\mathbf{R^A_{u_v}}$ exhibits textbook-like behavior
- little evidence for anti-shadowing in sea (and gluon)

evolve to 10 GeV²

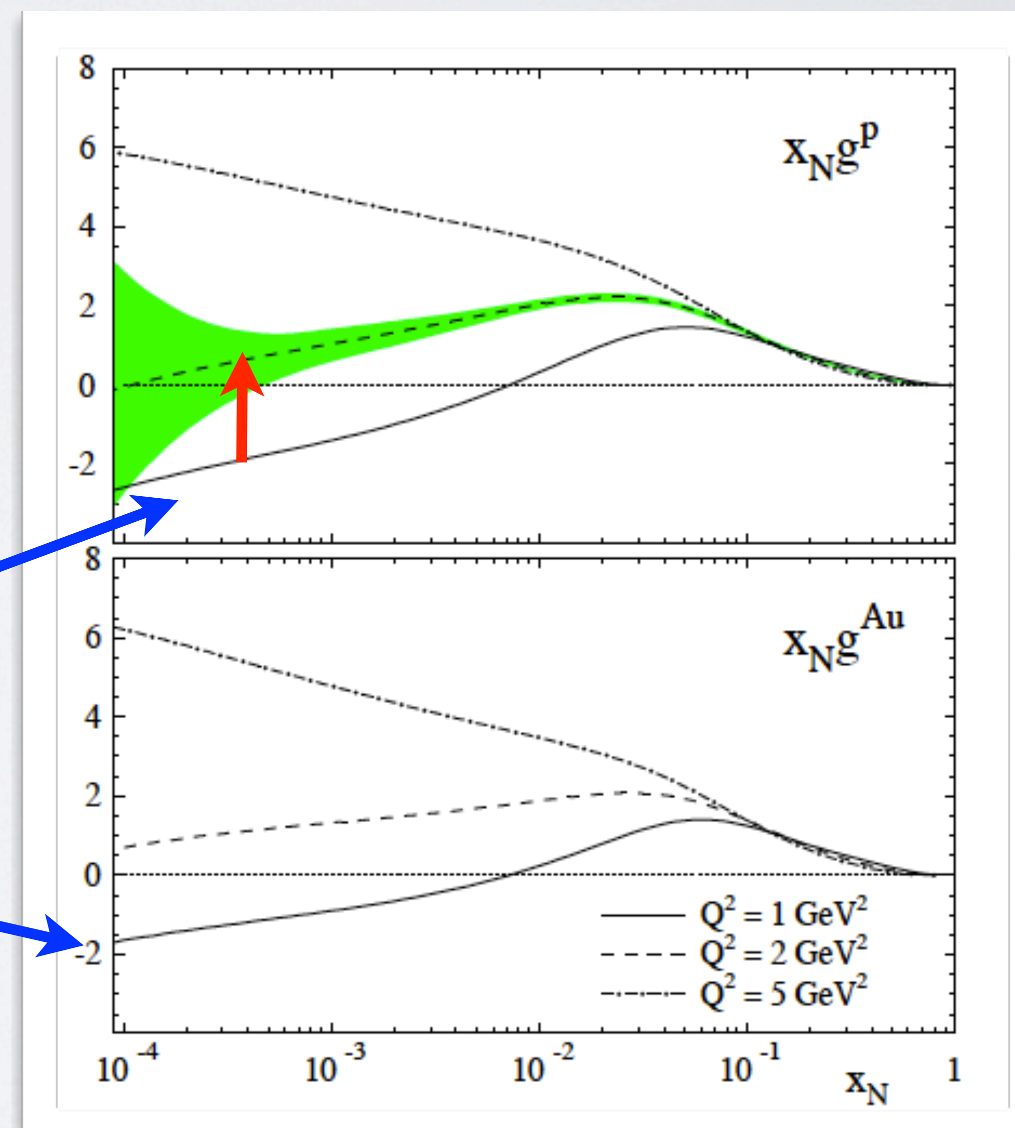


DSSZ: peculiarities



perturbatively generated charm and bottom nPDFs

- modifications for c,b follow closely the gluon
  no surprise, as they are generated from gluon splitting
- hierarchy in amount of low-x suppression:
  the stronger, the lighter the quark



the issue of "negative gluons"

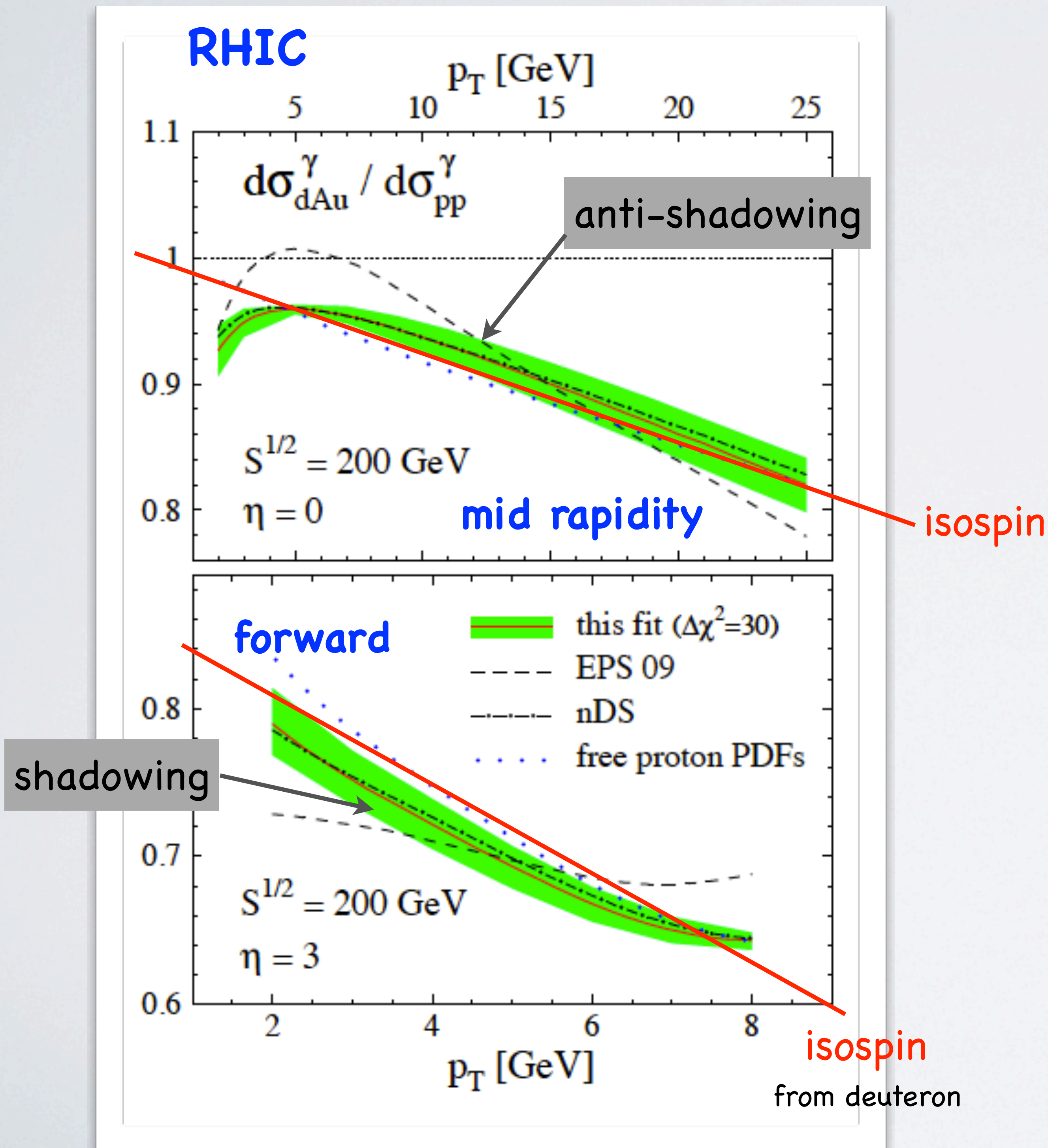
- MSTW exercises the possibility of **negative gluons** at small x and low scales [improves their fit of HERA data]
  not a problem since PDFs are not observables but F_L should stay positive
- evolution quickly pushes the gluon up
- our nPDF gluon is tied to the MSTW through R_g^A
  and gets negative too -> R_g^A ill defined at low scales (nodes)

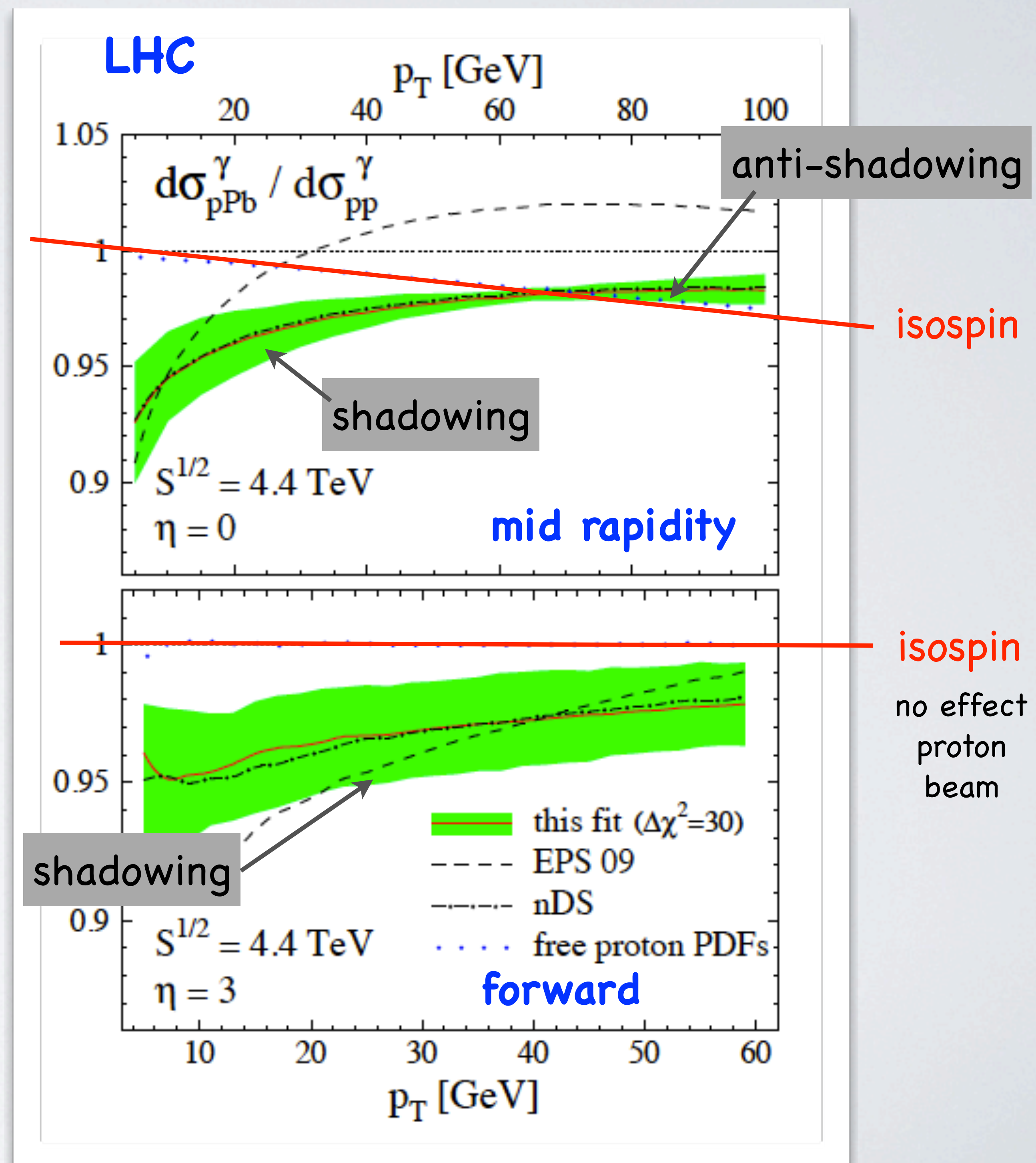
one must take trad. ratios R_i^A with a pinch of salt in NLO

4.3 Future: prompt photons

complication: "isospin effects" = dilution of u-quark density from neutrons $\mathbf{u^A(x) < u^p(x)}$

→ ratio dAu/pp not unity even w/o nuclear modifications





see also Arleo et al, 1103.1471

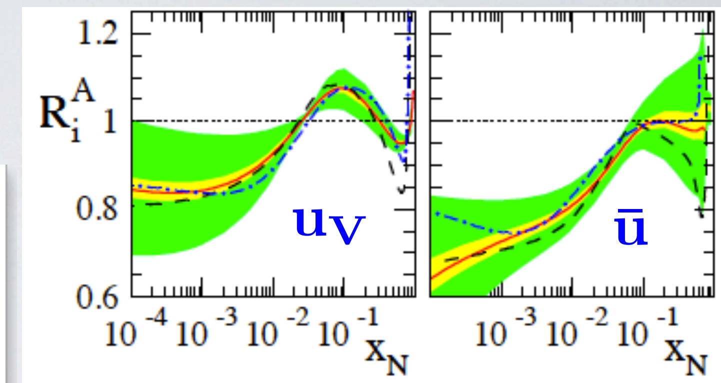
4.3 Future: Drell Yan lepton pairs

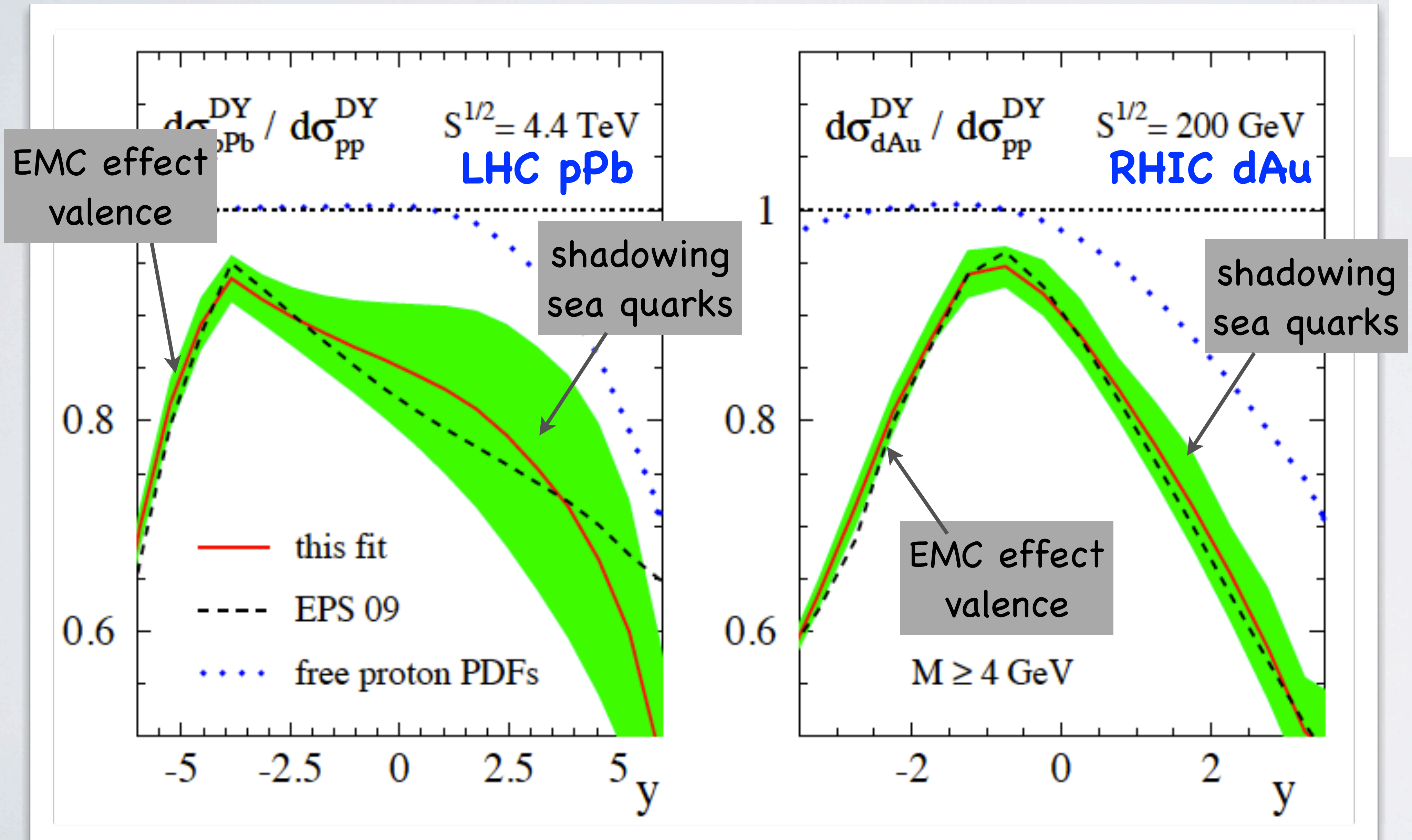
LO $$d\sigma^{pA}_{DY} \propto e_u^2\left[u(x_1)\bar{u}^A(x_2) + \bar{u}(x_1)u^A(x_2)\right] + e_d^2\left[d(x_1)\bar{d}^A(x_2) + \bar{d}(x_1)d^A(x_2)\right]$$

large positive y

large negative y

$$x_{1,2} = \sqrt{M^2/s}\, e^{\pm y}$$





x reach at y=3

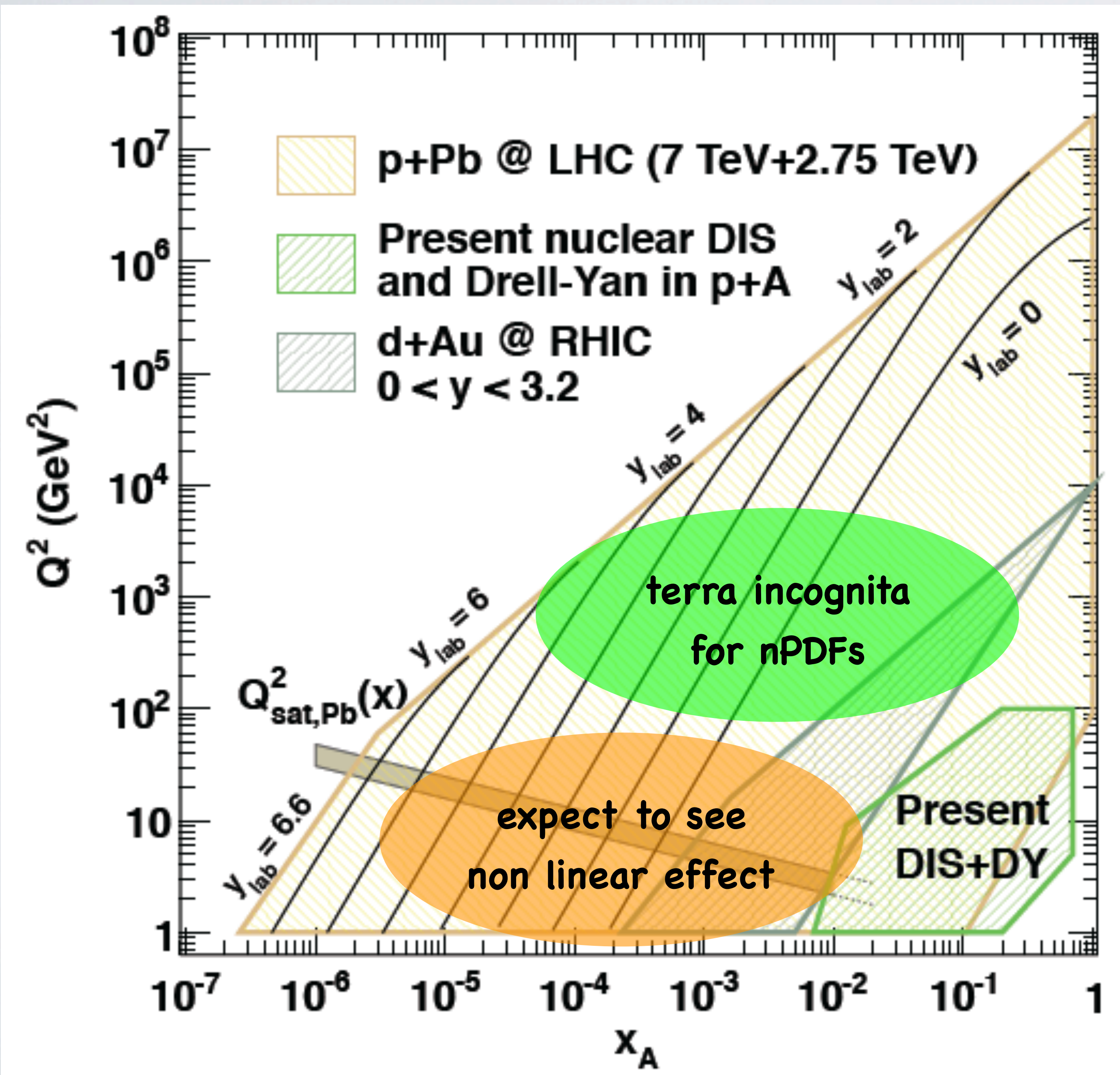
RHIC: $x_2 \simeq 10^{-3}$

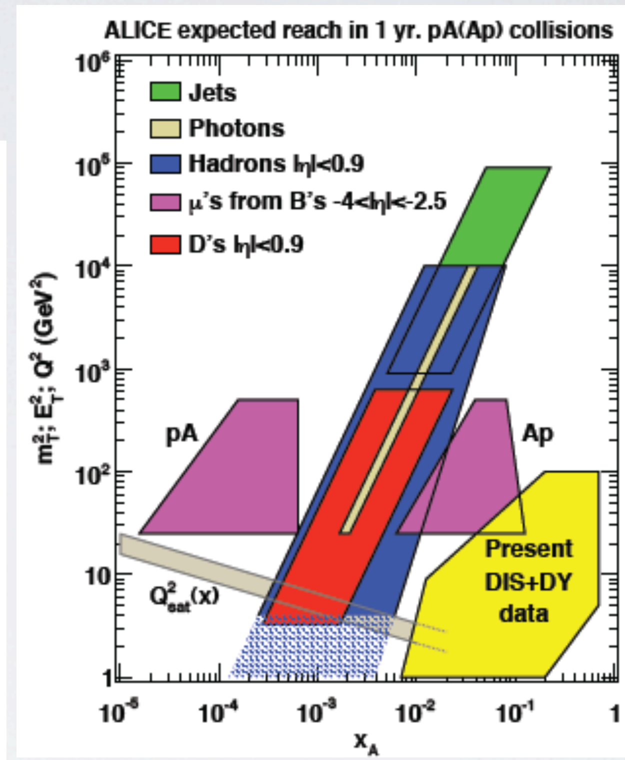
LHC: $x_2 \simeq 5 \times 10^{-5}$

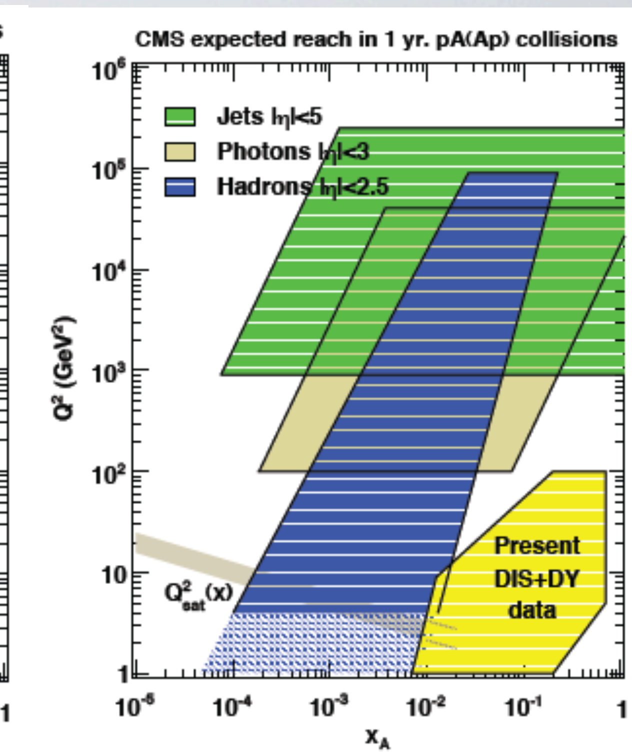
4.3 Future: pPb at LHC

see Salgado et al., 1105.3919

kinematic reach







- small x already accessible at mid rapidity
- many conceivable probes

expect great impact on nPDF fits

4.3 Future: eA at EIC & LHeC

PRECISION: direct access to nuclear partons through a leptonic probe

CONTROL: of the kinematic variables x, z, Q2 over a very wide range

CLEANLINESS no fragments from another beam

HERA for nPDFs

Examples:

in addition to the standard low-x saturation, nuclear environment studies,

gluon nPDFs F_L scaling violations

high precision CC program to check factorization/universality of nPDFs

high precision program to check medium modified hadronization (nFFs)

. . . .

1206.2913 1212.1701

Epilogue:

.... supposed to say something clever (bombastic?) about global analyses, PDFs, etc....

.... hmmm leave it as homework!

PDF customer satisfaction survey

How did you like global analyses?

What are their main pros and cons?

Do they affect your overall picture?

Can they improve your work? How?

Can your work improve them? How?

What would you like for Christmas?

Comments, complaints?

THANK YOU!

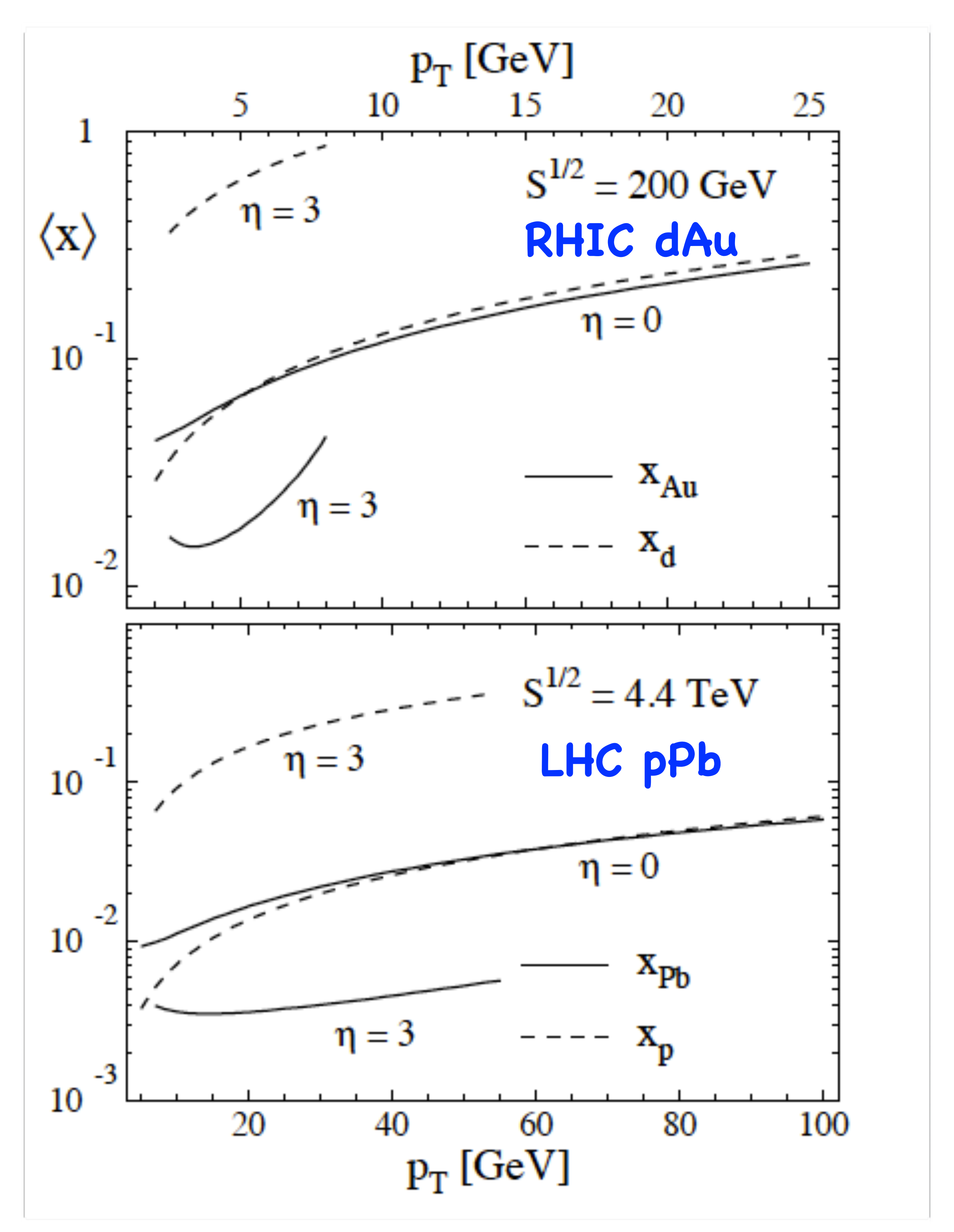
attention (patience!)

hospitality

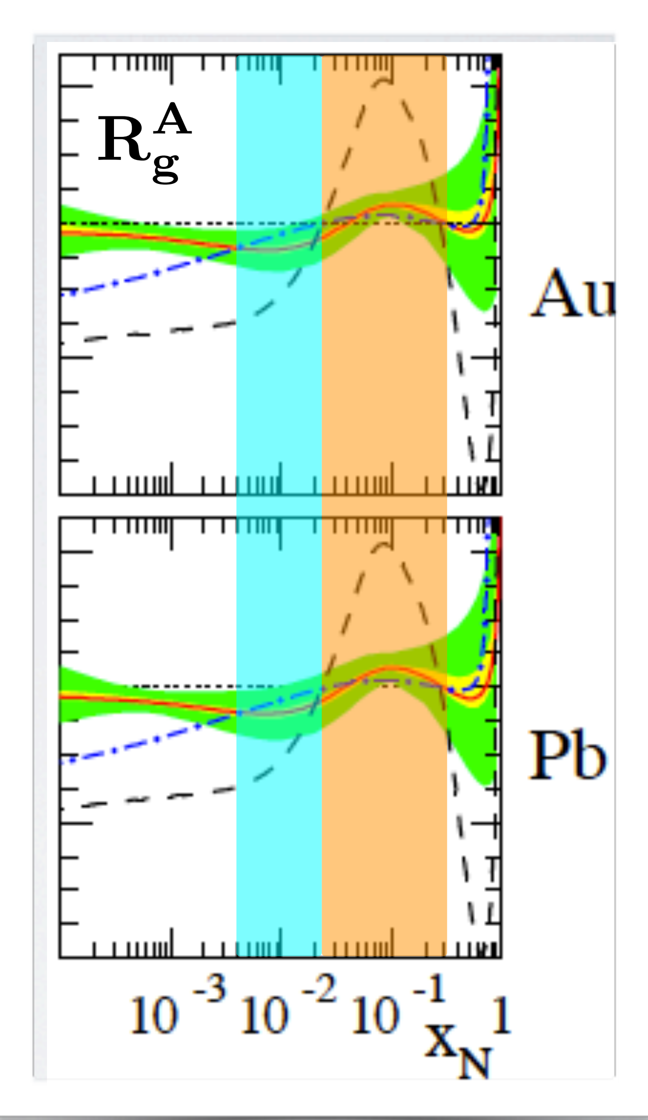
data!!

➡ sassot@df.uba.ar

4.3 Future: prompt photons



- can resolve characteristic differences between EPS and DSSZ gluons in anti-shadowing [and EMC] region



- can probe into shadowing region